le No. 73.

ing Secretary of your
Annapolis, Md. The
cations and communica-

L INSTITUTE,

members not receiv-
Treasurer of the fact.

UTE.

Vol. XXI., No. 1. 1895. Whole No. 73.

PROCEEDINGS

Please sign this receipt and hand it to the Corresponding Secretary of your Branch, or mail it direct to the Secretary and Treasurer, Annapolis, Md. The address given below should be the one to which *future publications and communications are to be sent.*

Received of U S. NAVAL INSTITUTE,

One Copy PROCEEDINGS, Whole No. 73.

Name, ...

Address, ...

The Proceedings are published at the end of each quarter; members not receiving their copies in due time will please notify the Secretary and Treasurer of the fact.

1873

EDITED BY J. H. GLENNON.

PUBLISHED QUARTERLY BY THE INSTITUTE.

ANNAPOLIS, MD.

PRESS OF
DEUTSCH LITHOGRAPHING & PRINTING CO.,
BALTIMORE, MD.

The writers only are responsible for the contents of their respective articles.

CONTENTS.

THE PROCEEDINGS

OF THE

UNITED STATES NAVAL INSTITUTE.

Vol. XXI., No. 1. **1895.** **Whole No. 73.**

U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.

FACE HARDENED ARMOR.

By LIEUT. A. A. ACKERMAN, U. S. Navy.

PREFACE.

The writer has long been impressed with the fact that the mode of resistance commonly ascribed to face hardened armor is incorrect. It seems that many have applied to it the theory upon which the development of compound armor was based. That is, the hard face was intended to smash the projectile without allowing penetration ; the body and back was to assist the face under impact, and to hold it together even after it had cracked and failed.

Modern improved projectiles are seldom crushed from the point. The point may be fused and abraded or chipped off in breaking up the hard face, but actual disintegration of the projectile only occurs when the resistance that the plate is able to bring on the area of the shell in contact with it is sufficiently great to suddenly check the shell and cause it to break up over its weakest lines through its own inertia. Failure at the point may, however, arise even with low velocities, when the resistance of the plate is less local, provided the energy of the shot is incapable of effecting penetration, or in the case of inferior projectiles.

The usual action of the hard face, however, is that through its inability to bend or flow, it prevents the displacement of the more plastic metal beneath it towards the front, and thus brings the resistance of the whole thickness of the plate to bear before the projectile can advance.

The important retarding influence of the fragments of the hard face carried in by the projectile, is seen in the easier perforation obtained by projectiles whose ogivals are protected by soft steel caps. The cap appears to act as a lubricant or sleeve, covering the asperities of the hardened metal. It is necessary for the cap to be driven into the plate to derive any advantage from it. Doubtless, when thus confined this soft metal transmits pressure as rigidly as the projectile itself, but being capable of flowing, the steel slips through it comparatively unharmed. It is believed that a thicker hardened surface, undulated to prevent or limit flaking, will cause the projectile to carry in sufficient of the hardened face to render the cap incapable of performing the work required of it without increasing its size to a prohibitory extent.

The writer has much for which to thank the officers with whom he has been associated in the Bureau of Ordnance in the way of information. Mr. Millard Hunsiker, now in charge of the manufacture of armor at the Carnegie Steel Company's works, at Homestead, has also kindly placed at his disposal valuable information. He also owes considerable to the Inspectors of Ordnance and officials at the works of the armor makers. These gentlemen are in no way responsible, however, for the conclusions reached. It has been the intention of the writer throughout to avoid discussing those technical details which have been developed by and are the property of the manufacturer rather than the patentee, and by means of which alone the process of face hardening can be made a commercial success.

SECTION I.

HISTORY AND MANUFACTURE.

Face hardened armor is the direct outcome of efforts to avoid the failures resulting from attempts to temper homogeneous steel plates of sufficiently high carbon to give a very hard face. It is theoretically the perfect armor plate, and doubtless would have been developed long ago had that theory only been enunciated; for the various steps followed in its manufacture, except in certain details, have long been known to the metallurgical world.

Lieutenant Jacques makes the following statement in a recent discussion of the armor problem: "We will not enter here into a discussion of the merits of those who have succeeded in getting their names attached to the various patented methods of surface

hardening, but hope that those who deserve it will get the pecuniary benefit. Ellis treated the first thick plate many years ago; Harvey revived this method, and with the assistance of the Navy Department secured patents which received attention from abroad because of the prominence our Navy Department gave them."

The writer does not believe that Mr. Jacques intends to imply that the Navy Department has the power to obtain or assist to obtain an illegal patent. The assumption that Mr. Harvey revived the Ellis patent is not correct. The old cementation process was carried on usually in cast iron or fire-clay pots at a much lower temperature than that now employed. Had Mr. Harvey proposed merely to cement or convert steel at a temperature above that of molten cast iron, a temperature which would soon have destroyed the old cementation pots, there would still have been considerable novelty in the claim. But Mr. Harvey proposed to do something more by using this high temperature: he proposed to improve the steel, to impart to ingots or other objects of low steel, such as Bessemer steel, the qualities of refined crucible steel! That he succeeded in this, and that his process is in this respect one of a number somewhat akin to it by which inferior steel is improved, must be known to every steel maker. Whether this particular process is essential to the cementation of such high grade material as that of which armor is manufactured, is a different question. It is certain, however, that the Harvey patents cover the process when carried on at that high temperature.

There is an error of minor importance in the article of Lieutenant Jacques above mentioned. The title of Figure "F," Bethlehem 17-in. N-Steel Carbonized, Indiana's Barbettes," is incorrect. Later, in describing Figure "Y," the attack of the same plate by Johnson capped shot, he again speaks of it as carbonized. This was not the case, and its perforation should not be charged against face hardened armor; had the Indiana's 17-inch Barbette plate been face hardened, the premium velocity shot would have smashed on it, as it did on the "Massachusetts" Barbette, instead of perforating it with ease.

The writer has the greatest respect for the energy and ability of Mr. Ellis, but if credit is to be given for the cementation of armor, he must share the honor with others.

We learn in Lieutenant Very's "Development of Armor for Naval Use" that early in 1863 a Mr. Cotchette submitted the following armor proposal to the English Iron Committee: "Upon an armor plate, say 3 inches thick, weld a surface of blistered steel ¾ of an inch thick; or 'convert,' to a depth of ¼ of an inch, the face of an armor plate 3½ inches thick, the plates being subsequently passed through a pair of rolls for consolidation and to reduce the blisters. The face of the plates could then be hardened."

As early as 1867, Jacob Reese, of Pittsburg, Penn., in patenting a cementation compound, proposed cementing and hardening the surface of armor plates. No attempt appears to have been made, however, to carry out his proposition. Ten years later, John D. Ellis patented an armor face hardening process in which a plate wholly of soft iron or having a steely part on either one or both faces had one or both of these surfaces cemented with charcoal in an ordinary converting furnace. This cementation might be effected either before or after the plate was reduced to its finished size.

In the same year, 1877, the Cammell-Wilson patent was allowed, in which two-fifths of the back of a hard steel plate was decarburized and softened, leaving the face hard and strong. The same firm at this time tempered low steel plates by plunging them in water, which rendered them tougher and more tenacious than when cooled in the air.

In August, 1877, the first Wilson compound plate was tested; this plate had a steel face and a four-inch wrought iron back.

In 1878, Wilson proposed soldering the steel face to the iron back by means of tin, zinc, spelter or bronze (a perfectly feasible method, by the way, which may yet be employed to secure thin armor to the ship). This steel face was to be formed of a number of hexagonal or other shaped pieces, in order to localize fractures.

Whitworth, too, proposed, for the same purpose, securing hexagonal plates of very hard steel to a softer back by means of screws.

At the Portsmouth trial of 1888, the "Jessop" plate consisted of a three-inch front cast steel plate, composed of twelve separate pieces of very hard cast steel fastened in a special manner to the seven and one-half inch rear piece of soft cast steel. The theory was that the laminations of the outside plate would localize

destruction and prevent the extension of cracks through the plate. This theory was found to be correct.

Thus far there seemed to be no consideration given to a mean between hard steel, containing about one per cent. of carbon, and which cracked and peeled from the backing, and soft wrought iron, which allowed perforation. The fact that steel could be made sufficiently *tough* to resist equally as well as compound armor without cracking, although claimed by Schneider, was generally denied by armor makers. No wonder that, under these circumstances, certain authorities made the assertion that physical characteristics had nothing to do with ballistic resistance.

In 1889, the attention of Commander W. M. Folger, U. S. N., the Inspector of Ordnance at the Naval Gun Factory, was attracted by a description of the Harvey process as applied to engraver's plates. At that time it was difficult to obtain steel suitable for gas check disks on account of its cracking in tempering, and Commander Folger concluded to try the Harvey process in obtaining the desired steel. A number of sets of rough steel disks were accordingly Harveyed, machined, and tempered, in a most satisfactory manner. Efforts were then made to Harvey a number of small caliber armor-piercing shell, the manufacture of which, in this country, was meeting with very slight success at that time. This attempt was made by grading the carbon from point to base in a foundation billet of mild steel afterwards forged into a shell. The carbon shell were, however, unable to compete with those containing chromium, and no great success was attained until long afterwards.

Commander Folger then decided to apply the process to armor by bringing the carbon in the face of a 28 per cent. carbon plate up to a point that would take a chill; the low carbon center and back retaining their softness. In this way he believed that the plate could be uniformly heated and cooled throughout, leaving it free from structural strains and with the minimum amount of distortion, defects which had been found to be very serious in certain tempered French plates of homogeneous steel. It will be seen that this was really an application of the Ellis process at a temperature higher than that usually employed in cementation.

The first experiment was not a success; the carbon penetrated three inches in depth, far beyond the reach of a true chill; but while

was improved in quality, rendered fine grained, soft and susceptible of hardening to a degree corresponding to the height of the temperature employed in cementation. His process was therefore distinguished from the old ones employed by the manufacturers of blister steel and improvers of steel for over two hundred years, as the "high temperature cementation process." Doubtless such an improvement occurs through the volatilization of deleterious components and change of structure in inferior metal, but analyses show that this is not the case in the superior quality of metal now employed for armor in this country.

In January, 1891, a 10.5" Schneider steel plate was Harveyed at Newark, tempered at the Washington Navy Yard, and tested at Indian Head. Its behavior was so excellent that a cementation furnace was at once erected at the Gun Factory and a number of experimental all steel and nickel steel plates of varying composition furnished by the Carnegie Steel Company were treated and compared ballistically with similar oil tempered plates. Upon the experience thus gathered, the first directions for finish Harveyed armor from regular makers was based.

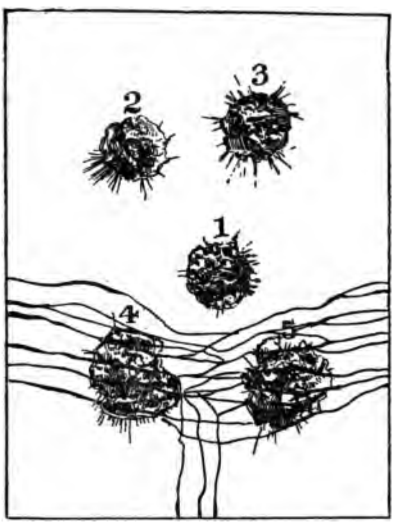
In September, 1891, three 10.5" plates were Harveyed at the Carnegie Steel Works and two at Bethlehem; these plates were employed in comparison with oil tempered plates to determine the relative resistance of high, .40 to .53 per cent., and low, .22 to .24 per cent. carbon, all steel, nickel steel, Harveyed steel, and Harveyed nickel steel plates. The Bethlehem high carbon Harveyed nickel steel plate was by far the best. The Armor Board, however, expressed some scepticism as to the accuracy of the carbon analyses.

In July, 1892, Bethlehem made two 10.5-inch Harveyed nickel steel plates, one forged to 12.5 inches, Harveyed, and then forged to 10.5 inches; and the other Harveyed at its final thickness of 10.5 inches. The resistance of these plates was phenomenal for that time, the latter being the better of the two, through defective tempering of the first.

In October, 1892, Bethlehem manufactured a 10.5-inch curved Harveyed nickel steel plate; and in January, 1893, a 14-inch plate was made by the same firm. Upon the tests of these plates, ranging in thickness from 3 to 14 inches, the requirements of service Harvey plates were based. It is only fair to the Naval Bureau of

Ordnance to note that the entire responsibility in case of failure, as well as the expenses and program for even the last details of treatment rested at this time upon it. Early in 1893, the first contract for service Harveyed armor was made with the two great armor making firms of the United States.

The temperatures thus far employed in cementation were stated to exceed 2500° F.; it is now believed that they were as a rule under 2010° F. Since that time many difficulties have arisen and been overcome; certain of these have been referred to the Bureau as unforeseen and concomitant to the process, and therefore lying within the sphere of its responsibility, so that the process as it exists at present, while giving full credit to the armor makers, is a result to which the Bureau has continually given its assistance.



BETHLEHEM 10.5″ PLATE ATTACKED BY FIVE 8″ HOLTZER SHELLS.
Note cracks confined to Harvey surface.

So many misleading statements have been made and so many doubtful claims advanced as to the advantage of great depth of carbon penetration, while the entire process seems susceptible of so many modifications and improvements, it would be best to describe briefly the various steps of the manufacture, and more at length the theories built on those steps. For it is a fact that the theories

both of cementation and hardening follow the practice but lamely and are open to numerous criticisms.

It must be understood that in describing a manufacturing process, it is necessary to draw the line sharply between the general plan or theory, which is doubtless fully protected by the patent, and the various practical details born of the manufacturer's experience and by which he makes the patent a commercial success, and the process economical and profitable.*

The information which is accessible to the public, however, in patent specifications, text-books, and the well-known methods of practical men in overcoming the difficulties to be encountered, is considerable.

The ingot from which the armor plate to be face hardened is forged must be even more carefully selected than in the case of oil tempered plates. The carbon gases in cementation seize upon and reduce the oxides found where defective welds exist, as in pipes, cold flaps and snakes, leaving thin fissures which are apt to extend and even fracture the plate in water tempering, owing to the lack of continuity of metal, breaking up and rendering the stresses irregular and unbalanced. In large ingots, especially when cast at too high a temperature and slowly cooled, the segregation of the metalloids, that accumulation of the specifically lighter and more fluid combinations of phosphorus, sulphur, carbon and silicon with iron, in the upper and central portions of the ingot where the metal last congeals, destroys its homogeneity and causes its thermal and physical characteristics to vary so much in a short distance as to practically amount to lack of continuity, especially under the extremely sudden and violent stresses of tempering. The segregation is composed of hard, brittle metal, and though its coefficient of heat expansion or contraction may not differ sufficiently from

* Thus, while methods of protecting portions of castings and forgings desired to be left soft from the action of the carburizing agents have been known as long as cementation itself, and specifically mentioned in numerous patents since 1867, a patent dated Nov. 13, 1894, was granted T. J. Tresidder for the broad claim of leaving the edges and portions of other surfaces of plates to be cemented soft in order to permit machining after hardening. This process of stopping off the carbon was recommended by Mr. A. E. Acker, late Assistant Engineer, U. S. N., at Bethlehem, in September, 1892, and was afterwards carried out by direction of the Bureau of Ordnance. It was also employed at Homestead on the experimental plates made in September, 1891.

that of the body of the plate to cause important stresses, still it is surrounded and braced by that metal and must expand and contract with it. This would not be serious in a slowly cooled or heated plate. In the case of a wide, thick plate quickly chilled on both faces, the exterior particles set over an expanded interior and are fixed while in a state of tension. Later successive layers of the interior cool and contract, placing the exterior in a state of compression, but these inner layers being then the more mobile of the two, instead of curving the exterior so as to wholly satisfy their contraction, are themselves placed in tension, gradually released in part by the yielding of the metal. This yielding must nearly correspond, unit for unit, with the remaining extension of the surface, otherwise there would be a sliding movement of one strata on the other. The tension is undoubtedly greater toward the center of the plate, however, as the edges of the strata cool earlier, and hence in a somewhat more expanded condition. It thus appears that very nearly the same amount of combined flow of particles and elastic extension is required over each unit of each strata of a uniformly cooled plate, increasing, however, toward the middle line, where in a segregated plate the metal is most brittle and least able to respond. Segregation in the ingot may therefore cause the internal rupture of a plate in tempering, no matter how uniformly and skilfully the plate be cooled. The recent failure of an 18-inch face hardened plate representing the Indiana's side armor was entirely due to this cause, the flaw being at right angles to the line of greatest contraction.

The armor plate is forged nearly to finished dimensions and rough machined, an allowance being made in its thickness to compensate for oxidizing of the back in the cementation furnace, as well as later scaling due to the bending and tempering heats. Allowances are also made in the length and width and the angles of the sides with each other and the faces, it being generally found that all faces will become convex, opening the bounding angles. The amount and method of application of these allowances are, of course, manufacturing secrets, varying for every thickness, shape, composition and treatment of plate.

The face of the plate is then carefully scaled. Abroad many of the experimental plates have been carefully planed off. The sand blast, as employed in cleaning castings, does not seem as

yet to have been utilized, although it is undoubtedly just as efficient and more economical than any of the other methods.

This scaling is very important, for not only does the film of oxide act as a non-conductor, retarding the heating of the metal, but it is necessary for the carbon to reduce this oxide before it can act in further carburizing the plate. This was well understood long before this process was applied to armor, for most of the early patentees of cementation processes and compounds indicate methods of cleansing the castings or forgings to be treated. When the scale is not removed the plate will have many soft spots.

Following the scaling, the "soft strips" or parts of the plate which are to remain untreated, in order that bolt-holes for deck or other fastenings may be made, are laid off, and the plate placed in the furnace with these parts opposed to a non-carburizing or sand bed instead of the carbon. All other parts of the face except a narrow strip about the edge, left, by direction of the Bureau, not only for finishing, but to diminish as much as possible the tendency to form edge-cracks in tempering, are cemented. This process of limiting the operation of cementation has also been known and practiced for many years.

Plates of slight curvature are bent before carburizing; those of large curvature are bent afterwards before tempering. In this later bending operation superficial cracks occasionally occur in considerable number. These will be discussed later. Whatever the shape of the plate, a bed to correspond is swept in sand on the floor of the the furnace, and upon this is placed a six-inch layer of the cementation compound, be it Harvey's or Pettino's mixture, or, for that matter, any one of a number of patented combinations which, upon being heated, produce carbon or hydrocarbon gases, and claim to obtain practically the same results. The Harvey mixture is probably nearly as cheap a mixture approaching a standard of uniformity as is at present manufactured; it is not peculiar in its action, however, and abroad other carbonaceous compounds are generally employed. It is composed of equal parts of animal and wood charcoal, the former being the expended "char" from sugar refineries. The combination is patented, the claim being that the heavier animal charcoal gives the light, powdered wood charcoal a body, enabling it to be handled without waste or the danger from explosions which result

from heating a mixture of air and such combustible dust. The wood charcoal probably acts more as a dilutent and cheapener of the "char" than anything else; the mixture, however, renders up more slowly and uniformly its gases than would otherwise be the case, although it is stated that the approved method at present is to place a half-inch layer of pure animal charcoal next the plate. A too rapid introduction of the carbon destroys the grain and strength of the metal, making it resemble pig iron. The great thickness of the layer is rendered necessary by the volume of gases required to be generated in the long process, which exhausts the material, as well as the importance of gradually obtaining and maintaining a high and equable temperature. The great thickness of non-conducting material between the flues and the plate makes it a long operation to obtain the desired temperature, but once reached, sudden fluctuations are impossible.

The plate being placed in the furnace, its sides and back are covered with sand or loam, rammed down, then a layer of fire-brick, the furnace cover is placed in position and the ends walled up. At the Carnegie Steel Works, where natural gas is used, a platform car forms the bottom and sides of the furnace, and this being charged is run into its housing and the fires started.

There are many varieties of cementation furnaces, each claiming special advantages, the important feature of all being the obtaining of a uniform and high temperature by surrounding the brick or fire-clay flask with furnaces and flues conveying the products of combustion towards the stack.

The furnaces using natural gas and oil are probably the most costly, on account of the numerous valves required, but once erected they are the most convenient and permit a nice adjustment and variation of the temperature. They are doubtless also more rapid in their action if desired.

The original furnaces employed by Mr. Harvey were very slightly different from the old-fashioned cementation furnaces; they used coal; afterward oil burners were introduced. That erected at the Naval Gun Factory in the winter of 1890–'91 used soft coal, and those built at Bethlehem in 1891 are similar. Two regenerative furnaces at Homestead were temporarily converted into cementation furnaces in the summer of 1891, but their present splendid plant of twelve gas furnaces was built in 1893, and are

entirely different from and regarded as superior to the old type of furnaces.

The difficulties to be guarded against and overcome in working these furnaces, no matter what the fuel, are very great. The high temperature and the great weight and size of the charge, as well as the long time required, prevent the use of iron flasks such as are used in cementing small articles, for even should the white-hot iron fail to break down under the weight, it would quickly oxidize and become unserviceable. Fire-brick or other forms of intractible material must, therefore, be used for the lining of flues and flasks. These expand largely and become extremely tender at a high temperature, introducing other dangers from settling or collapsing, by means of which air may gain access to the carbonaceous material, which is then quickly consumed and the metal fused. To raise an armor plate weighing between thirty and forty tons to the temperature of from 2230° F. to 2500° F., required by the Harvey process, and keep it there for weeks, supported on brittle fire-brick, is to run a serious risk.

These considerations, and the great expense of the process as at present applied, led the writer to investigate the practicability of reducing the temperature and time of cementation at one and the same time. The problem seemed difficult, especially as it was claimed by some that the process, even when carried out with the utmost skill and patience, was hardly a controllable one, and that a variety of results from apparently identical conditions might always be expected. The project of increasing the cooling surface of an armor plate in tempering, by corrugating or gashing its surface, was recalled, and the feasibility of employing these enlargements of the surface at an earlier time to expedite the cementation seemed unquestionable. This germ of an idea quickly expanded and the proposition became—to cover the face of an armor plate with a series of gashes, or pockets, or corrugations, by means of which the area, over which the carbon or other cementing material could penetrate, might be multiplied, and an equal percentage of carbon introcuced into the superficial layer in a proportionately less time than in the case of a plane surface. These enlargements to be so proportioned as to permit the maximum percentage of carbon to extend in to a greater or less depth according to the thickness of the plate, thence shading off into the body of the plate so

as to prevent a too sudden transition of grain and extensibility along a single plane—that of the inner limit of the chilled surface—in order to avoid the flaking off of this surface under impact.

The impracticability of rolling or forging such a surface down after cementation without leaving it covered with defective welds, cracks, or seams, was apparent from the first. The writer had, however, been much impressed by the numerous severe tests of Gruson chilled iron armor, from 1882 to 1890, in which it was shown that cracks confined to the chilled surface in no way reduced the resistance, and never originated, extended, or gave direction to the cracks due solely to impact. The success of Sir Joseph Whitworth's experimental plate, in which his proposition "to prevent cracks by manufacturing them" was exemplified, seemed also to indicate that such superficial defects, far from weakening the plate would prevent flaking and the extension of cracks. This conclusion was at this time supported by the excellent behavior of a face hardened plate, the surface of which was covered by a network of cracks formed in rectifying, and soon after by that of three other plates tested to destruction. In fact, on one of these plates the cracked surface was more resisting than the sound, which was to be expected, as the chill was able to enter more deeply where the edges of the cracks permitted deeper contact of the cooling agent.

Another feature of the proposition is that as the various ridges and corrugations would attain the desired temperature far earlier than the flat surface of the plate; this would reduce the time of the process materially, especially as it would not be attempted to obtain the peculiar advantages claimed from the use of a high temperature, as in the Harvey process, at all. The intention being merely to introduce a certain percentage of carbon into the superficial layers of the plate in the same manner, and at the same temperature that cementation has been carried on for many years past.

Such a process would be extremely useful when applied to rectangular blocks for the sea faces of forts, turrets and floating defenses having no room for a slope. These blocks would not necessarily be forged and shaped to the extent and accuracy of dimension required for ship armor. There are many existing fortifications of little defensive strength on account of the exposure

of their masonry faces to attack, these could be protected at comparatively little expense by deeply cemented face hardened armor. There are also locations such as Roma shoals, Race rocks, etc., where turrets will be required protected by armor of this description.

It is evident that any new process which at one and the same time permits practically the same results to be obtained at a much lower temperature and in less than one-half of the time now required will be of great value, as not only will the output of a furnace be more than doubled and the cost of fuel and labor per ton of output less than one-half, but the life of the furnace will be much longer and the time, labor, and materials expended in repairs largely reduced.

The advantages claimed for the proposed process are, however, by no means confined to the reduction of the cost of manufacture. It is firmly believed that a more resisting armor can be made in this manner than is at present possible by any other process.

It is also proposed to expedite, in a measure, the heating of the charge by placing numerous pins of good conducting material in the bed of the furnace. Fluctuations in temperature will be hardly more possible than at present, while time will be saved by heating the non-conducting mass as a whole rather than from one surface.

When thin plates are cemented, a number are placed in the furnace face to face, with a layer of the carburizing material between. (This plan was first employed at the Bethlehem Iron Works early in 1893.) Embedded in this are wrought iron tubes, extending from end to end of the furnace, and in these are placed the test rods, which can be withdrawn from time to time for inspection, without admitting air to the interior. Their color, from end to end, indicates the uniformity as well as degree of temperature of different parts of the charge, and the various flues are dampened or burners and fires regulated accordingly.

When the desired temperature is reached, determined either by the color of the bars or by means of a pyrometer employed at one of the tube openings, the fires are regulated to maintain that temperature for a greater or less time, according to the thickness of the plates.

Considerable time is lost in gradually cooling the charge, as it cannot be exposed to the air at a high temperature, as oxidation

and scaling would result, the plate might also be chilled or air hardened. Especially is this the case with nickel steel, the nickel seeming to render more sensitive and to increase the hardening capacity of the carbon, so that the difference of the effect of cooling in the air of a cold, moist climate as that of Sheffield, England, and the dryer, warmer atmosphere of Pittsburg or Bethlehem might cause the difficulty said to be found abroad in machining unhardened carburized nickel steel, and which our armor makers have been able in a great measure to avoid. The plates are then air annealed from a cherry red in order to break up the large crystals in the cemented face.

After carburizing, analyses are made at various depths from each end of the plate, to determine the percentage and depth of carburization. The plate is then machined and bent to such shape and dimensions as experience indicates will most nearly result in those desired after hardening. This machining, as a rule, includes all work done on the hard face, although an electric annealing apparatus has lately been devised, by means of which the hardened metal may be softened locally when desired.

The plate is then carefully heated to the temperature required for hardening, the hardness and depth of chill increasing, within a certain limit, with the height of temperature to which the plate is heated. It will be seen at once, the higher the temperature the more plastic the metal and the greater the distortion. The lower the temperature can be kept and still produce a hard surface the better for the manufacturer, as the subsequent rectification will be less difficult.

The plate being heated to the desired temperature is placed upon the tempering stand, and a powerful spray from a large number of small, evenly spaced jets is forced upon both sides of it. This spray is modified from time to time as required to keep the plate in shape. After the plate's exterior has been thoroughly chilled, it is lifted into the oil bath and left there until cold. Occasionally a plate will be found that will not respond to treatment, becoming distorted, in which case the process is repeated. In so doing, of course, there may be a loss from scale as well as the oxidation of the superficial carbon. If the plate is but slightly out of shape it may be bent cold under the press; this, however, frequently causes the hard face to crack in a most alarming manner. The effect of these cracks, however, on the ballistic resistance is, as has been stated, of no consequence.

Finally, the plate has its bolt holes tapped in the back and is finish-machined, it sometimes being necessary to employ an emery wheel, or electric annealing, at the hardened edges to obtain the desired perfection of joints and butts.

A great difficulty in the treatment at first was the oxidation on the back of the plate; there is no loss from the carburized face unless it is overheated. In England a clayey cement has been used with good results. At St. Chamond it has been the custom to decarburize the back of the plate in order to render it more ductile while carburizing the face. It is doubtful whether any benefit is derived from this, however, unless the plate later receives some forging. It is also said that plates are very much improved after cementation by a careful annealing in carbon. Doubtless, if armor plates are machined after cementation, a thorough annealing before hardening would remove any stresses liberated by the removal of the surface metal, and which would tend to complicate and render those introduced in tempering unmanageable, otherwise the annealing seems expensive and unnecessary except, of course, when the plates are removed from the cementation furnace at a temperature sufficiently high to be air hardened.

The effect of water hardening a face hardened plate varies not only with the depth of the strata of metal but with its composition. Careful analyses show that in good plates the normal carbon may be found at a depth of of 1.25″, but that the effect of water tempering will be found to reach to the heart, increasing the strength and toughness to a remarkable degree even though the normal carbon may not exceed 25 per cent. Vickers' claim to obtain this effect at a depth of seven inches inches in a ten and one-half inch plate is fully justified by facts.

SECTION II.

CEMENTATION.

The practical features of the manufacturing of modern face hardened armor having been discussed, it will be interesting to note the present state of the theories of the two important steps, *cementation* and *hardening*.

The art of cementation was practiced by the ancients. Tubal-Cain made steel by surrounding iron with charcoal and exposing it to the long continued action of a comparatively low and slowly penetrating heat. Later, furnaces were constructed which could be sealed so as to exclude the air to avoid melting or oxidizing the charge, while the higher temperature employed permitted the carburization to be carried on rapidly.

In Landrin's Treatise on Steel is given an interesting account of experiments made by Réaumur in 1722 to determine the best compound with which to convert iron into steel. For this purpose, Réaumur used not only the materials commonly employed for case hardening in France, but specially prepared and exploited mixtures, as well as certain formulas said to have been obtained in Germany. Iron bars were heated in crucibles with various inert substances, such as sand, potter's clay, ashes, glass and lime, "the only apparent change being a loss of fibre in fibrous iron and a diminution of thickness of lamellae in laminated iron."

Various salts and alkalies were also tried, without difference of effect, in combination with these inert substances. Oils, when mixed with sand or clay, burned off and were lost before the metal was sufficiently heated. A combination of oils and alkaline salts, as soap, or soot with charred horn and leather, however, was found to transform the iron into steel.

"Charcoal, soot, or old burned leather, of themselves, produced a fine, hard steel, difficult to work, and even after forging full of flaws and cracks. Pit coal, powdered and sifted, had a very rapid effect, diminishing the volume and corroding the metal which became hard and fine, but harsh steel."

His conclusion was that powerful alkalies helped the conversion, but the resultant steel was difficult to work, full of flaws and incapable of welding or drawing out. A peculiar effect occasionally produced by certain salts, as sal ammoniac, green vitriol, etc., was that the steel was not lasting, for when forged and hardened once, it had a fine grain, but forged and hardened a second time, it had scarcely any grain. Finally, common sea salt was regarded as the most suitable for the conversion of iron into a fine, hard steel, easily worked and lasting.

"The composition which answered the best for converting iron into a very fine and hard steel is 2 parts soot, 1 part powdered charcoal, 1 part ashes, and ¾ part of common salt.

"The formula should be varied to suit the iron. The greater the percentage of oily matter, found mostly in the soot and charcoal, the more rapid the process, though the steel is apt to be flawy and hard to work. Increasing the percentage of ashes slows the operation and diminishes the deleterious effects; the minute proportion of alkali in the ashes acting as a carrier, the earthy matter as a moderator. The salt is not absolutely essential, but it hastens the operation, adding to the fineness and hardness of the steel as well as largely reducing the amount of composition required. Increasing the amount of salt increased the flaws. In converting irons tending to become harsh, 1 part of lime or calcined bones might be added with the result that a steel otherwise impossible to forge could be easily worked." One-eighth part of lime added diminished the blisters which later gave a name to this kind of steel.

So much for the published knowledge of the process of cementing steel 175 years ago. Since that time a large number of processes have been advocated, and it will be interesting to note the more or less reliable claims of some of these.

In 1859, a Mr. Johnson patented "a cementation compound of equal parts of quick-lime, bone dust, and wood charcoal, which, after an intimate mixture, was exposed to dry weather for several days." He explains "that this enabled the lime to absorb carbonic acid from the atmosphere, by which means he obtained the necessary carbon in the purest and most convenient form." He found that Swedish or Danemora iron "containing so much P as to give an odor of it when twisted at a red heat" is cemented much more rapidly than other irons. "A bar of such iron $\frac{3}{16}''$ thick being converted completely in two hours, while a similar bar of English iron was converted but $\frac{1}{16}''$ deep in the same time." Believing that P was essential, he added bone dust on account of the basic phosphate contained, which either enters into combination with the iron or, by more or less doubtful catalytic action, aids in accomplishing the same result. This mixture could be used again and again after each operation by exposing it to the atmosphere so as to take up CO_2, and adding a small amount of lime.

The fact is, of course, the highly oxidized lime probably took up moisture by selection of H from the air as well as C from the carbon present in the charcoal.

The presence of P was regarded as important by the late Mr. Harvey, who found that the operation was rendered much slower and less effective without P, and that the bone charcoal was therefore the most important ingredient in his mixture. As, however, the basic phosphate is not reduced at the usual temperature of cementation, its effect can hardly be due to the absorption of P by the metal.*

In 1861, Mr. Weston explained the action of a mixture of cyanide of potash and charcoal as follows: "The cyanide is decomposed by heat into cyanogen gas and potassium, and the first upon contact with the metal is broken up into C and N, the C uniting with the iron while the N unites with the charcoal, and in the presence of the potassium forms another portion of potassium cyanide. Any compound of cyanogen with an alkaline metal may be used."

It has been asserted by M. Frémy that cementation cannot take place without nitrogen. This is not so, cold iron buried in powdered charcoal absorbs carbon even without the aid of heat. Nitrogen is merely a convenient gaseous carrier. Under the effect of heat it combines with carbon present, forming the easily decomposed cyanogen gas which penetrates the expanded pores of the metal and weakly gives up its carbon to the iron. If hydrogen is present, a small proportion of H_4N is formed, which accounts for the ammonia gas found accumulated in the shrinkage cavities of castings or often perceptible when metal is fractured.

In 1868, a Mr. Sheehan places in the bottom of his retort fragments of limestone covered with a perforated plate, and above that a carbonaceous mixture of 200 parts of charcoal saturated with water, 30 parts of muriate of soda, 12 parts of sal soda, 5 parts each of black rosin and black oxide of manganese. "On heating, the carbon is expelled from the limestone and unites with the oxygen and carbonaceeus ingredients above to convert the iron."

In 1875, M. Eyqueur employed peat with 1½ per cent. ammoniacal salt, preferably hydrochlorate. He states that "the carburization takes place under the simultaneous action of ammoniacal

* It is the writer's opinion that P acts as a reducer of CO; it is well known that the value of P in phosphor and manganese bronze is due to its reduction of CuO.

and carbureted hydrogen gases, the iron passing to a state of zoto carburet and the rapidity depending upon the nascent condition of the gases."

In 1891, Brown's compound was patented; it is composed of 87 per cent. pure carbon, 8 per cent. calcined lime, 4 per cent. soda ash, and ½ per cent. each of tungstic acid and sal ammoniac.

The action is said to be that "the soda ash frees the metal of oxygen, opening the pores or intermolecular spaces, while the calcined lime eliminates the oxygen set free or remaining in the retort. The bone carbon then commences to throw off its carbon, and with the help of the ammoniacal gas generated from the sal ammoniac a pure cyanogen gas is generated which permeates the metal, carrying with it the free tungstic acid which tends to give the metal greater hardness."

In 1893, a Mr. Hunter patented a compound of 25 parts muriatic acid, 16 of salt, 32 of chloride of lime, 32 of carbon. The action claimed is that "hypochlorous acid, $HClO$, generated in contact with the heated carbon and metal by which it is decomposed into Cl, O, and H, the oxygen and hydrogen taking up carbon and with it penetrating the iron, the operation being facilitated by the presence of the Cl. The salt may be omitted but is important when the metal contains considerable silicon."

In MacIntosh's process, wrought iron bars were suspended in a furnace, the walls of which are highly heated; de-sulphurized coal gas is then passed through. The process was very efficacious, though expensive.

There are also many gaseous methods of cementing steel, that of Schneider, for example, in which a highly heated retort contains two armor plates placed face to face and separated by a frame work at the edges, thus forming a chamber into which hydrocarbon gas at a constant pressure is introduced at a high temperature. There are also numerous other processes of combining the cementation and improvement of iron and steel, by heating in the presence of carbonaceous mixtures. The explanations of very few, however, are satisfactory, and the claims of many others are based on assumptions which are far from being generally accepted as scientific facts.

The processes may be divided into groups, as they employ gaseous and solid or liquid compounds. Probably all are really

gaseous in action, for it is difficult otherwise to explain the transfer of solid carbon from the distant and large sized lumps of charcoal employed in the old cementation process. It has also been found in cementing armor that the carbon gases at times penetrate considerable thicknesses of sand and impregnate the steel beneath.

The movement and commingling of atoms of many different substances when closely associated is known to occur under the influence of heat. The well-known experiment of Sir Lowthian Bell in which smoothed discs of cast iron of 3.25 per cent. and wrought iron of .04 per cent. carbon, were tightly bolted together and heated in a furnace for one month with the result that the cast iron lost 1.07 per cent. and the wrought iron gained .348 per cent. carbon, would seem to indicate at first that the carbon gained, under the influence of heat and pressure, something of the freedom of a gas. Still the enormous volume of elemental gases contained by the cast metal, renders such a conclusion unnecessary. This is also the case with the old method of cementation, in which a heated bar was stirred in molten highly carburized cast iron and then quenched; or in the comparatively late process, in which iron is cast directly upon the face of an iron or low steel plate and then exposed to severe heat for a long period of time with the result that the carbon gradually becomes so distributed as to destroy the plane of demarkation.

This interchange of atoms is not confined to carbon alone, for it is noted in the Journal of the Iron and Steel Institute, Vol. I., 1889, p. 368, that the welding of iron to nickel brought about the transposition of atoms. For after dissolving off the iron back it was found that the percentage of iron in the nickel had increased from 0.9 per cent. in the original to 3 per cent., the normal percentage of iron being found only at a depth of .45 of the thickness of the nickel. Iron is stated to be volatile at a medium red heat, for when alternate sheets of nickel and iron are heated to redness for some time, the former increases in weight through absorption of iron, a true alloy of iron and nickel forming at the surface of the latter. Whether the nickel has a special influence, or whether this volatilization is going on at all times and in all directions from heated iron is not stated. It would therefore seem that the iron has the power to meet the carbon half way, both being volatilized and possessing affinities, when, of course, the formation of a definite carbide would naturally follow.

In Sir Lowthian Bell's Principles of the Manufacture of Iron and Steel, he demonstrates the readiness with which carbon is deposited at and up to a red heat in iron sponge from carbonic oxide. In the Journal of the Iron and Steel Institute, Vol. II., 1891, he also notes that nodules of iron oxide in the bricks lining the flue along which the gases for a blast furnace were conducted caused the deposition of carbon from carbonic oxide which penetrated the bricks, thus cracking them apart. Mr. Snelus also found that red brick in flues took up enormous quantities of carbon from the gases, one brick containing as much as 45 per cent. of carbon.

Sir Frederick Abel also stated before the Iron and Steel Institute in 1892: "The carbon impregnation of an iron ore takes place at as low a temperature as de-oxidation, which in Cleveland ore occurs between 392° F. and 410° F. At that temperature freshly reduced spongy iron reduces carbon from carbonic oxide to an extent corresponding to 20 to 24 per cent. of its weight, but as the temperature approaches a red heat, the deposition of carbon diminishes considerably in amount. The increased effect of a nascent condition of both iron and carbon is here apparent. Experiments also showed that nickel, and to a smaller extent cobalt, suffer reduction from their oxides (below red heat) with deposition of carbon."

In the Encyclopædia Brittannica is found "The process of cementation is that of the occlusion in the iron of CO formed by the combination of C with the air in the charcoal. This is then decomposed by the iron into C and an iron oxide, which is then reduced by a second portion of CO.

Thus (1), $Fe_x O_y + {}_yCO = Fe_x + YCO_2$,
and (2), $Fe_x'' + YCO = {}_yC + Fe_xO_y$.

The CO_2 penetrates less readily through the metal than the CO, and in doing so forms blisters." This seems hardly probable. It is much more probable that the CO_2 having satisfied its affinity is the only gas left in evidence in the presence of the oxidized scale or blister.

Judging from the statements made by Sir Lowthian Bell and Sir Fred. Abel, the formulas given in the Encyclopædia are correct for low temperatures; Sir Fred. Abel states, however, that as the temperature approaches a red heat, the deposition of carbon largely diminishes.

As the temperature at which carbon combines with iron in the carbide Fe_3C lies at about 1200° F., it would appear that above that temperature the carbon must be associated with the iron in another form, perhaps merely deposited, while the carrying gas, be it N in cyanogen, O in the oxides, or H in the hydrocarbons, joins some more volatile substance present, or escapes in the elemental condition.

At the highest temperature it is probable that the following formulas would be more nearly correct:

(1) $2Fe_x + YCO = Fe_xOY + Fe_xC_y,$

(2) $Fe_xO_y + YCO = Fe_x + YCO_2.$

From this it would appear that when the O present is exhausted the process must stop, a conclusion which agrees with the practice of renewing exhausted compounds by aeration.

The iron exposed in the pores has a capacity as Fe_3C for one-fourteenth its weight of C. In the entire mass only 63 per cent. of that has been found of combined carbon.

The changes in volume of the metal in solidifying and cooling are very irregular; thus, steel on congealing expands, on cooling contracts, but in the latter case neither regularly nor continuously. There are three points of recalescence or evolution of heat accompanied by an increase of volume in cooling from a temperature slightly over 1800° F. These, according to Mr. Osmond (see Journal of the Iron and Steel Institute, 1890, Vol. I.), are: 1st. A slight evolution of heat at about 1562° F. 2d. A very faint ovolution of heat at about 1382° F. 3d. A point, absent in mild steels but strongly marked in high carbon steels, at 1200° F. These "critical points" and their meaning are discussed in a valuable paper on the Physical Influence of Elements on Iron, by Prof. J. O. Arnold, in the Journal of the Iron and Steel Institute, 1894, Vol. I. The highest critical point is considered to be due to chemical changes accompanying the evolution of hydrogen. That at 1380° F. is regarded as physical, due to the passage from a plastic to a crystalline condition; and the lowest is due to the combination of iron and carbon into the definite carbide Fe_3C.

Undoubtedly the process of cementation is affected by the various conditions of expansion and structure of the metal found between the normal temperature and the melting point. There

are reasons for believing, however, that no advantage will be obtained by exceeding 1832° F., all of these phenomena being manifested below that temperature. Above it, the metal is regarded as contracting to the melting point, the pores are diminished in size and the carbonizing gas has become extremely attenuated. Doubtless the greater molecular activity at this high temperature will permit a considerably greater absorption of carbon in the surface layer with an abrupt reduction to the normal percentage. The time required to reach and cool down from this temperature, the cost of fuel, together with the greater risk and uncertainty, render the high temperature less satisfactory than another method which may be proposed. That is, by corrugating the surface or covering it with shallow pockets, the walls of which being thin will be affected much earlier and at a lower temperature than the massive body of the plate. Later these irregularities may be forged down if desired.

Percy says that pure carbon will not cement, and that it will only continue to combine while gaseous matters are given off. It is evident, however, judging from the most successful and rapid-carburizing agents, that the process of cementation is best carried on by a compound which under heat influence liberates an easily decomposed carbon gas. This, penetrating the pores of the metal in a nascent condition, combines readily with it, especially if the iron be freshly reduced. This is known to be the case with hydrocarbon gases, and cyanogen, and is believed to be the case with carbonic oxide and dioxide. Any material which when heated would continuously render up these gases would enable cementation to be carried on. Above the temperature of 1200° F. this process is probably effected, in the case of carbon gases, by the deposition of carbon and the formation of an iron oxide. The latter may be reduced by CO with the formation of CO_2 which passes on into the metal repeating the operation, the smaller volume of C, and the less degree of completeness of each succeeding operation, causing a gradual diminution of the carbon deposited.

It follows, therefore, that if a larger surface of metal is exposed to the action of the gases, as by gashing or scarifying the surface of the plate, the process will be greatly expedited, the volume of gas directly in contact with the plate being not only much greater

but at work at the same time over the entire depth of metal to be treated.

Hammered iron is said to be more rapidly cemented than rolled iron perhaps on account of the rough scale left in the latter case. It is also said that the porosity of steel is generally in an inverse ratio to its tensile strength; this is not always so, still it is very certain that the low tensile requirement before treatment makes possible the employment of a steel which takes up the carbon very readily.

The process of cementation also reduces the amount of sulphur present; according to Boussingault, one-half at least is volatilized in the form of a carbon sulphide. This doubtless refers to inferior grades. It would seem that by the disengagement of volatile matters associated with the iron, the latter would be left in a receptive condition, favorable to rapid cementation.

The heavier the charge the longer must it be maintained at the temperature of cementation to obtain the same depth and percentage of carbonization; in fact, the amount of carburization in equal times varies approximately inversely as the volumes of the charges.

The temperatures at which the cementation is carried on varies greatly; that employed in the manufacture of blister steel is about 2100° F., that for the Harvey process, "above the temperature of molten cast iron," must exceed 2228° F. The desired effects, however, have been produced in about the same time at as low a temperature as 1750° F., and many excellent armor plates have been cemented at a temperature never reaching 2000° F. In fact, little if any of the excellent face hardened armor manufactured at Bethlehem has been cemented at a temperature above that of molten cast iron. At Carnegie's the temperature has also been reduced, it is believed with benefit to the metal. That found most satisfactory abroad is said to be 2000°–2050° F., which is below the melting point of even white cast iron. It is probable that with greater experience European armor makers will reduce the temperature.

The time required to reach the required temperature varies; a plate 6.4″ thick required 4 days, and the temperature was maintained 6½ days, after which it was allowed to fall. In the case of a 9.5″ plate, these times were respectively 6 and 8 days. These plates were of excellent quality.

The percentage of carbon required on the surface by the Bureau of Ordnance is that which will not through its regular diminution reduce the depth of chill given by the hardening process, limited and regulated as it is to prevent distortion.

SECTION III.

HARDENING.

Henry Marion Howe explains the effect of hardening in improving the strength and toughness of steel as follows:

"Dissimilar rates of contraction produce a kneading effect. There must be between the various layers considerable kneading pressure and rubbing; and as this, in kneading dough or putty, through compression; in forging, through compression and tension; in molasses candy, through tension, appears to increase the intermolecular cohesion, so we may ascribe to this feature of hardening the increased strength and toughness." . . . "The hardness proper is due to the maintainance of the chemical condition existing at a red heat, but the changes in tensile strength and ductility to a joint effect of chemical and physical origin. Annealing may obliterate all the effects of sudden cooling except that due to the kneading of the metal, which resembles forging and increases the strength, so that by proper management we may increase both tensile strength and ductility by tempering and annealing."

The Société de Châtillon et Commentry claim to have established the fact that soft steels simply cast, after being lead tempered, have the properties of forged steel. The process, however, requires great knowledge of the conditions for making the steel, the temperatures to maintain varying very sensibly with the nature of the metal.

M. Pourcel, of the Terre Noire Works, has also long contended that all the benefit of forging can be obtained on large castings by a proper course of treatment.

It is the idea of Frederick Siemens in tempering glass that by uniformly cooling every part of the body of the glass, no matter how rapidly this is done, the contraction of the mass—the cessation of molecular movement—is uniform and there are no strains introduced. Granted that no *irregular* strains would be introduced,

such as snap a tempered steel shell, still there must be minute balanced couples of stresses which hold the molecules together with greater tenacity than in the case of ordinary glass.

If these couples making, perhaps, an enormous aggregate, are irregularly disseminated among the weaker couples of ordinary glass molecules, then those stresses tend to develop which so frequently cause the spontaneous fracture of tempered articles. Such a condition must result when steel is heated too rapidly or irregularly. The carbide is not uniformly disseminated, the metal is not uniformly expanded, and the result of rapid cooling cannot help but accentuate these irregularities until perhaps the surface is covered with cracks or the metal actually flies to pieces.

It is difficult to conceive a rearrangement of molecules causing a body to occupy a larger volume according to the degree of hardness when chilled than when slowly cooled, without the introduction of stresses. It seems probable that the unsatisfied affinities of the carbon for the iron, existing, however, only during a very brief period of the cooling, places the whole body in a state of constraint. There is strong doubt that at any subsequent period of cooling these stresses are released by a conformity of the molecules, as each instant their movements become more difficult; besides a shrinkage of the mass would hardly satisfy a chemical affinity.

Professor S. P. Langley has demonstrated that it is possible to somewhat harden steel from a temperature no higher than that of boiling water, which would indicate the continuance of a very powerful affinity, as the movement of the atoms must then be extremely difficult. Similarly it is known that severely hardened tools have been found with the lapse of time to have become tougher and less brittle hard.

The hardening tendency is said to be proportional: (1) to the amount of carbon, hence the volume of chemical attraction; (2) to the rapidity of cooling, hence the proportion of that attraction unsatisfied; (3) the height and duration of the temperature of hardening, hence the amount of carbon dissociated from the carbide and disseminated among the grains of iron.

At a temperature above 1200° F. the carbon existing in the form of a carbide of iron, irregularly coagulated in the steel, commences to disintegrate and dissolve itself through the mass of metal. This

movement is undoubtedly the more difficult the less the metal is expanded and heated above the temperature of chemical combination. The more slowly the metal is heated to the higher temperature, the tougher it becomes without loss of hardness; this toughness increasing with the length of time of exposure to that temperature. The higher the temperature of hardening, within limits, the deeper and stronger the effect of the chill. Upon cooling the metal slowly, however, the carbon again seizes the iron and with the aid of the forces of chemical affinity and incipient crystallization again becomes segregated.

The range of maximum hardening effect has, therefore, for its upper limit that temperature at which the heat dilation first overcomes the chemical attraction, and for its lower limit that point where the chemical attraction is no longer able to move the sluggish atoms.

"If the steel be long exposed to a high temperature, say a light red or orange, it assumes a coarsely crystalline structure which it retains in cooling, and its toughness and strength are greatly impaired. The more slowly the steel is cooled within reasonable limits the softer and tougher it becomes, the major part of the effect being produced in cooling from a cherry red to scarcely visible red.

"The best general results in hardening are produced by quenching from the lowest temperature which will produce the desired result. The more rapid the cooling the harder the steel and, up to a certain point, the greater the tensile strength, but if very violent the strength may be diminished. The lower the C the more rapid should be the cooling to give the greatest advantage."—*Howe.*

The rapidity of cooling, in turn, depends upon the cooling medium. "In general, the greater the specific gravity, specific heat, mobility, latent heat of gasification, coefficient of expansion, and thermal conductivity, and the lower the boiling point and the initial temperature of the cooling media, the more suddenly will the immersed metal cool."—*Greenwood.*

The thicker the piece the greater the chill required to produce the same hardness.

Experiments show clearly that the transmission per degree of difference between hot gases on one side and water on the other

side of a plate was directly proportional to that difference, the total transmission therefore being proportional to the square of the difference. The more smoothly machined the faces were the less efficient in transmitting heat. This might be expected, as the rougher they are the larger the heat transmitting area.

Caron concludes, after experimenting with mercury, water containing different salts, covered with oil, or containing syrupy or mucilagious matters, that the *degree of hardness* and other effects appear to be inversely proportional to the square of the time of cooling the metal.

Chernoff says, with regard to cooling in water, the conductivity of hot metals is very small, and that although the external visible parts soon show the desired fall of temperature, yet the central portions remain very much hotter. In fact, while the specific heat increases with the temperature, the conductivity decreases, iron losing nearly 25 per cent. between 0° C. and 100° C. This evidently limits the depth of "chill" obtained even with the most violent treatment, no matter what the composition of the plate.

The fact that in a thin plate there is a smaller accumulation of heat to be dissipated in chilling than in a thick one, indicates at once that, as the hardening effect is due to the rapidity with which the temperature is caused to fall from redness to 450° F., and that as the specific conductivity of the metal diminishes as it becomes hotter, the heat transmitted between two points, while varying nearly directly as the difference of temperature, is less and less for that difference as the interior of the plate is approached. At the same time the outer layer parts with its heat with a rapidity nearly due to a flow from a mean point between redness and 450° F. to water of 40° F. This is, of course, hardly the truth, the heat of the surface being dissipated mainly in the specific heat of the spray and the latent heat of its vaporization, rather than by conduction. Nevertheless, the exterior layer being reduced thereby, almost instantly, to a certain temperature t, the second layer parts with its heat with a decreasing rate as its temperature falls and approximates that of the first. The result is a rapidly decreasing rate of fall of temperature as the surface is receded from. This rate decreases almost as rapidly for another reason, that is, that the specific heat of the hot metal is considerably greater than that at the surface, so that even if the flow of heat was equal at the two

points, the interior would require a proportionally longer time to fall a degree than the exterior. So long, therefore, as the claim is upheld that hardening is due entirely to the carbon in the steel, and the rapidity of the fall of its temperature, there will be a point quickly reached beyond which the metal cannot be chilled; and so long as certain elements, as chromium and nickel, are believed to have no power in themselves of hardening or increasing the conductivity of the metal, their effect in delaying the change from hardening to cement carbon cannot be very important, so far as increasing the depth of the chill is concerned.

The advantages to be gained by breaking up the surface to be hardened by gashes and ridges are manifest from the above. The comparatively small volume of metal in the ridges may be given the same hardness with a less severe chill than the unbroken surface of the plate. This means that the quenching temperature may be lowered and the distortion diminished. At the same time, the fissures will permit the body of the plate to be more rapidly cooled, thus increasing its toughness.

The phrase "decremental hardness," as applied to face hardened armor is very misleading; so far as hardness pure and simple is an advantage to such armor it is usually confined to a comparatively thin and uniform layer, below which the metal exists in a decrementally toughened, rather than hardened, state. At the same time, hardness with its consequent brittleness is to be avoided at a great depth, as the plate will tend to split.

It is known that there is no difference whatever, under the elastic limit, between the extension, for equal stress in equal lengths, of soft and tempered steel. Mr. Edmonds, of the Woolwich Gun Factory, stated in 1891 before the Iron and Steel Institute that the modulus of elasticity is scarcely altered by oil-hardening. That is, for example, a nickel steel armor plate whose elastic limit in the untempered condition is 46,000 lbs., and when tempered 66,000 lbs., would stretch equal amounts for equal stress in each condition. In the first case, however, permanent deformation would begin with a stress of 46,000 lbs., and in the second with 66,000 lbs.

Mr. J. G. Dagron has also found by a series of experiments that the permissible compression load on iron and steel columns varies, not as the strength of the material, but as its modulus of elasticity.

It is in fact the modulus of elasticity which chiefly concerns us, as the superficial hardness given highly carbonized metal by water-quenching is very different from that obtained in oil-tempering, and largely increases the modulus of elasticity. Steel has been obtained having a tensile strength of 400,000 lbs. per square inch with practically no flexibility and very little elongation. The enormously increased modulus of this metal over that which it possesses in the annealed condition, indicates in a fair degree its increased resistance to compression, abrasion, and puncturing, in fact its hardness.

At a certain point beneath the surface of a face-hardened plate, depending upon the severity of the chill and the percentage of carbon, the original modulus may be found. The elastic limit and the tensile strength below this point have, of course, been raised, the former proportionately more than the latter, but the extension per unit of stress under the elastic limit remains practically uniform to the back of the plate. Towards the face, however, the modulus increases, at what rate or to what extent it is impossible to say. It is merely known that the hardness does not in every instance correspond with the depth of the chill. By the "chill" being understood the fine, bright, and uniformly grained surface layer, sharply divided in appearance from the heterogeneous interior of the plate. The thickness of this layer varies with the composition and treatment of the steel from a barely perceptible film to about 0.6″. Although the metal below the chill may be very hard, its uniformity in appearance leads to the supposition that the change of modulus does not occur within it, but rather with the change in character of the metal at the border of the chill, thence increasing towards the face. This assumption is supported by the fact that flaking, due to the unequal elastic extensions of adjacent layers, occurs principally at this depth, seldom or never below it, and often outside of it. Doubtless the difference in the structure of the metal may account for the flaking, as well as the change of the modulus; that they are coincident, however, seems unmistakeable.

The existence of flaking, in that it indicates the sudden release of stresses exerted in resistance to shot penetration over a considerable area is a serious defect. The chill, however, is not always so sharply divided from the metal below; in fact, certain

Harveyed plates have not flaked at all, the metal around the impact chipping out in wedge-shaped pieces, showing a more gradual diminution of hardness; such plates crack. The sharp line of demarcation of the chill is perhaps due in some cases to checking the spray from time to time to permit rectification in hardening. Such a procedure would tend to cause laminations of varying hardness, more or less distinct as the rapidity of cooling is greater and the temperature higher, from which the plate is cooled.

The action of the hardened face under impact is to bind together the tougher elastic particles beneath, opposing the extension produced by a depression of the surface. If the under metal at the surface of the chill extends, it must either crack the face or shear away from it. It seems, therefore, that if the chilled surface occupied the faces and sides of a large number of narrow and shallow gashes in the face of the plate, so as to be sharply broken up, flaking would be prevented. At the same time the surface would be more rigid and braced against, as well as preventing the extension of the metal below. Such gashes need not weaken the plate, as they would be confined to the hardened surface, which is otherwise bound to crack and flake before the interior is extended.

Theoretically the depth of surface chill should vary with the caliber of the projectile to be resisted; for while the zone of its resistance to the advancing ogival increases with that caliber, and the surface already crushed down with its square, the energy of the shot varies with the cube. Efforts to resist greater energies by making the body and back stronger by an increased percentage of carbon have usually led to the plate cracking under impact.

Attention must be paid, however, to the limitations of carbon steel in hardening and toughening. Also to the fact that the change in tensile strength due to tempering follows a different law than the hardness.

Both the tensile strength and ductility of the mildest steel are greatly increased by quenching, though the hardness may be scarcely changed. The same result will be produced on higher carbon steels quenched from a temperature below that affecting the carbon, although, as noted previously, Professor Langley has to a small degree hardened steel by sudden cooling from the temperature of boiling water.

It is evident, therefore, that the more sudden and complete the chill, the greater the increase of toughness in the body and back of the plate. Should the metal be highly carbonized for any considerable depth, however, it would not only lack strength and toughness, but the contraction strains might cause it to crack and flake off spontaneously or at least under impact. If the chilling should be made less severe, or from a lower initial temperature, in order to avoid these external defects, the interior might hardly be toughened at all. It appears, therefore, that as the depth of chill now obtained must in all probability be increased if projectiles of the latest type are to be resisted, the present system of carbonizing and hardening would not be satisfactory. To get the chill in deeper, the carbonization must extend deeper, and the percentage on the surface be higher; this would require greater time and expense in the cementation. In hardening, the higher carbon in the face would prohibit quenching from as high a temperature as now employed, not only on account of the danger to the plate, but on account of the much greater difficulty in controlling or preventing distortion. Should the surface of the plate, however, be covered with fine shallow cracks or serrations spaced from seven-eighths of an inch to an inch and a quarter apart, it would be possible in cementation to give the metal a practically uniform and moderate percentage of carbon to the bottom of these grooves, from which depth it would shade off quickly to the normal. Upon hardening, the surface through which the heat is abstracted having been thus enlarged, it would be possible to chill much deeper, considering the intentionally low content of carbon, than is at present possible.

"Changes in hardness are almost entirely due to changes in the carbon, apparently closely following the changes from cement to hardening carbon. The increase of hardness is practically proportional to the amount of carbon; it is not due to the stresses set up, because both interior and exterior are hardened, though under opposite stresses; also thin bars are hardened more than thick, through cooling more suddenly, though their stresses are less severe. At the same time, while pure iron is placed under violent stress when quenched, still it is not hardened. This is in opposition to Ackerman's theory that the changes in hardness, ductility, structure, and much of that in tensile strength is due *entirely* to

compression which forces the carbon into the hardening state; this theory is plainly incompetent."—*Howe.*

Still, Caron found that blister steel after forging contained more hardening carbon than before, and that pressure favored the absorption of charcoal carbon. On the other hand, the effect of compression, as an aid in hardening steel, has been long known. At Moutluçon pressure was applied to steel in hardening when at a cherry red. Liquid steel containing more than 0.50 per cent. carbon is sensibly hardened if cooled under a pressure of from 7 to 10 tons per square inch. The proportion of combined carbon is always greater under pressure than when the metal is uncompressed. M. Clemendeau, in hardening steel for tools, places the cherry red metal in a receptacle it completely fills, and then subjects it to enormous pressure; the greater the pressure the harder the steel.

The fact undoubtedly is that hardness is primarily due to the carbon. Professor J. O. Arnold in a recent essay on the Physical Influence of the Elements on Iron, read before the Iron and Steel Institute, makes the following statement: "That no element except carbon has (*per se*) the power of conferring upon quenched iron the power of abrasion hardness to any extent worthy of consideration. Whether the adamantine hardness of quenched high carbon steel is due to the individual properties of an extremely attenuated carbide of iron or to an allotropic change produced in the iron itself, by the presence of dissolved carbon, there is no evidence to show, nor is the matter of much practical importance since such hardening power is possessed by carbon alone." These are strong statements and yet correspond to the general opinion of metallurgists, although there is still a considerable diversity of opinion among them.

When, however, the method and degree of hardening effect produced by a certain percentage of carbon is considered, it will be found that the chemical composition, rate of cooling, pressure, and temperature, all exert important influences; and to these in consequence have frequently been ascribed the results which, however modified, really pertain to the carbon alone.

Thus high carbon steel cooling past the critical point at 1200° F. undergoes a molecular change made manifest by the evolution of considerable heat, sufficient in amount to retard the cooling. It

is said that from this point the metal becomes more and more dense as heated until fluid. The fluid density of steel, the composition of which is not stated, has been given as 8.05 ; in the solid state it was only 7.8. This evolution of heat at 1200° F. is accompanied by a contraction of .004 (Barrette) in a steel containing 0.9 per cent. carbon, which, occurring wholly in the small percentage of carbide formed, must be much greater there. However, by compression the tendency of the metal to expand below the point of recalescence in the formation of carbide is opposed, and the effect of contraction by cooling produced, and hence the cooling is hastened by the further evolution of heat. Doubtless the great depth of chill in cast iron projectiles can be explained by the magnitude of these forces, as that operation increases the specific gravity of the metal fully 3.5 per cent.

A substance expanding in congealing or liquefaction may within limits be compelled to retain its denser state against the influence of heat by sufficient pressure. Conversely, when a body upon being heated expands, it may be led to part with its heat more readily in cooling if subjected to pressure. The same effect is produced on the solution of a salt by pressure as if it was a solid melting.

Professor J. Thomson considers the following to be a physical axiom : "If any substance or system of substances be in a condition in which it is free to change its state [as ice, for example, in contact with water at 0° C. is free to melt], and if mechanical work be applied to it as potential energy in such a way that the occurrence of the change of state will make it lose that mechanical work from the condition of potential energy without receiving other potential energy as an equivalent, then the substance or system will pass into the changed state. Thus the lowering of the melting point by stress is the cause to which is attributed the plasticity of glaciers."

Steel test pieces often show a fracture, the center of which is grey, becoming brighter towards the edge, when, if broken without tension, the fracture is homogeneous. W. Hempel ascribes this to the combination of the carbon under pressure. The increased strength obtained in wire drawing and cold hammering is explained in the same way.

The application of pressure is undoubtedly therefore an important assistance in tempering. It may be said that the molecu-

lar attraction, constantly in opposition to the dispersive action of heat, is assisted by pressure, although the latter may only be felt in the exterior layers of molecules.

It is believed that the pressure brought to bear in hardening on the surface layer of a carbonized plate by the initial contractions of the walls of the gashes or cracks, above spoken of, would correspond in its effects to an increased percentage of carbon or a more violent local quenching, thus forming an additional reason why a certain depth of chill could be obtained with a lower percentage of carbon and less danger of distortion.

COMPOSITION OF ORIGINAL PLATE.

Before continuing it is important to consider the influence of the composition of the original plate; bearing in mind the fact that the effect of water tempering should not be confined to hardening the surface, but include a marked toughening of the metal throughout.

On this subject there will be found a great diversity of opinion. Generally speaking, however, this arises from the confusion of the influences exerted by a component on an existing steel alloy with the characteristics *per se* of that component. Liberal quotations are made from the valuable discussions by Professor Arnold, Osmond, Hadfield, Brustlein, and others, before the Iron and Steel Institute.

The presence of chromium in the original plate is advantageous for several reasons. Ordinary cemented cast steel has large crystals, while those of cemented chrome steel are small. M. Brustlein, of the Holtzer Works, at Unieux, France, says: "In chrome steel *the temper penetrates deeper* than in plain steel, having an equal amount of carbon. This is attributed to the great affinity of chromium for carbon, favoring the dissolution of the latter in the metal, and thus maintaining it with greater readiness in the combined state. In manganese steel the same thing occurs; in fact, a small amount of manganese hastens the chilling effect. Chrome steel, however, scales badly, like nickel steel, and the difficulties of its manufacture are very great. First, it requires an intensely high heat for reduction; second, incomparably more rapid solidification than mild steel occurring in the change from

white to yellowish white heat; third, the formation of an oxide when exposed to the air which cannot be reduced or entirely separated from the mass of the steel; these difficulties increase with the size of the ingot; fourth, very great shrinkage; fifth, highly carbonized chrome steel burns very easily."

Generally, chromium has a less hardening tendency than manganese or highly carburized steel, but it imparts more tenacity, and the tendency to crystallize by excess of heat is not so great. Manganese steel works better hot under the hammer than chrome steel, but the former works particularly well anyway. Again, manganese steel welds with great facility, while chrome steel welds badly or not at all. "Steel containing a high percentage of carbon and chromium, especially the former, as .77 per cent. C, 5.19 per cent. Cr, will harden when cooled in the air. It is, consequently, self-hardening. Heretofore it has been believed that tungsten compounds alone had this property."

M. Brustlein also says "chrome steel is especially valuable on account of increasing both tensility and elastic limit without diminishing elongation, as would occur in carbon steel, where an increase of tensility invariably means a decrease in ductility." M. Brustlein is wrong there, as Howe has shown how proper treatment of carbon steel increases both elongation and strength. He, Brustlein, says chromium steel also seems to harden more readily. Chromium plays the part of a hardener, even without the intervention of a cooling medium; therefore when such a medium is employed the hardness is intensified.

Hadfield declares: "It has not been proven that a piece of chrome steel of a given diameter would harden more deeply when quenched than a similar piece of carbon steel.

"Probably if the right hardening temperature were obtained for each *class of steel*, it would be found that the chromium steel was tougher after hardening than the carbon steel, and it is also probable that it would harden at a somewhat lower heat, but *that the effect of hardening would penetrate further is not proved.*

"Theories have been advanced that chromium holds carbon in the combined state and that therefore chrome steels harden more readily. Seeing that the carbon present in all steel is in the combined state, whether chromium is present or not, this explanation does not offer much satisfaction. Chrome steel gives great resist-

ance to compression, but in the absence or lowness of carbon it has in this little or no superiority to similar aluminium or silicon steels. So long as the carbon is about .30 per cent. or under, the effect of chromium crystallization is small, but when the carbon is greater the action is more vigorous, or the carbon is enabled to act more vigorously."

F. Osmond, in the Journal of the Iron and Steel Institute, 1887, Vol. II., says: "Manganese retards both the molecular change of iron and recalescence during cooling from a high temperature, or in other words, maintains the carbon in solution and the iron in the condition β, the effect being greater in proportion to the amount of manganese. The same effect is produced by the rapid cooling of steel containing no manganese, so that the presence of manganese exerts much the same influence as the process of tempering, a conclusion which agrees with the known mechanical properties of steel containing manganese. Tungsten has the same property in a still more marked degree; but *chromium appears to produce no similar effect.* Silicon has no influence on the effect produced by manganese (it hardens of itself, however). Sulphur seems to neutralize part of the manganese, diminishing its action. Phosphorus has no appreciable effect on the modification of the iron nor on recalescence."

From the remarks of Mr. Hadfield it would appear that, in order to obtain any characteristic effect of chromium in the heart of an armor plate, it would be necessary to run the carbon there up to a prohibitory point, although the cemented surface would obtain the full benefit of it. In France this difficulty has been to a certain extent overcome by combining the chromium with nickel, which seems to act as a sensitizer, emphasizing the hardening effect of the carbon in the chromium alloy, while retaining the necessary ductility; in fact, toughening the metal rather than rendering it hard and brittle. The celebrated *açier speciale* of St. Chamond is also a chrome-nickel alloy, said to contain .40 C, 1.0 Cr, and 2.0 per cent. Ni.

All of Vickers' Harveyed plates are said to contain some chromium; it is also found in some of Brown's and most of Schneider's. It is extensively used by the French in their protective deck plates, the principal feature of which are their extreme ductility and toughness.

In the United States no extensive experiments have been made with chrome steel armor, the difficulties of manufacture of which are indicated above by M. Brustlein. It is believed that as our armor at present compares very favorably with the Harveyed nickel chrome of St. Chamond, which has been developing for some years, that more is to be expected from an alloy of nickel manganese. In this connection, it is interesting to note the effect of manganese on carbon as indicated in Professor J. W. Langley's equations of annealing and chilling. These were published in the Transactions of the American Society of Civil Engineers, Vol. XXVII.

(1) Power of annealing $= \frac{\text{Si}}{\text{Mn} \times \text{C}} \times t.$

(2) Power of chilling $= \frac{\text{Mn} \times \text{C}}{\text{Si}} \times \frac{1}{t}.$

A recent process, in which a mild steel body and back are cast upon a bed of ferro chrome and then water hardened, deserves attention. After experiencing the usual difficulties accompanying the development of a new process, most satisfactory results are claimed to have been obtained, the percentages of chromium and carbon averaging about 5.5 per cent. and 1 per cent. at the face respectively, and running out to the normal in 1.5″. If the resistance of the face hardened cemented plate was entirely due to the hard face, rather than a tough body bound together by that face, it might find in this cast plate a dangerous competitor on account of its cheapness. It is feared, however, that the result cannot but resemble somewhat a cast, homogeneous, chrome steel plate, the body and back of which have been weakened.

In this connection, it is worth while to note that M. Montgolfier, Directeur de St. Chamond, declares that although their celebrated chrome-nickel armor increased the velocity to perforate armor of a thickness equal to the caliber of projectile 100 meters, the application of the Harvey process raised that velocity fully 100 meters more.

SECTION IV.

THEORY OF ITS RESISTANCE.

The empirical formulas for the perforation of wrought iron plates differ so widely in their results, as the thickness of the plates or the calibers of the guns vary, that they have been called a disgrace to the science of mathematics. This seems like blaming a good servant for not accomplishing the impossible.*

When it is considered that these formulas represent forced generalizations from a comparatively small number of experiments in which the actual qualities of projectiles and armor, often merely guessed at, were assumed to be identical, the diversity of opinions is explained.

Steel often varies considerably in its composition from heat to heat as well as being strongly influenced by many conditions of temperature and treatment in the course of manufacture; it is therefore much more liable to variations in quality than wrought iron, and fewer general laws as to its behavior can be made. The problem was attempted, however, and the De Marre formulas, believed to be fairly accurate for Creusot steel plates, resulted. In these the projectile is not supposed to experience any change of form while passing into and through the target. As this condition is rarely fulfilled under the conditions of test, there is usually a certain amount of the projectile's energy expended on its own deformation, with a consequent relief to the plate. Especially is this the case when the deformation is of the nature of an expansion of the shell, thus increasing the area directly opposed to its advance. When the plate is hardened, tending to check the projectile suddenly and to crush or break it up, the energy thus diverted is still greater, while that remaining, being distributed among fragments acting in detail, produces proportionately less effect. Evidently the *calculation* of the resistance of a single plate of this description, even though the method and extent of its actual resistance had been determined by experiment, would be complex enough; and if it is sought to generalize, the irregularities in quality are so great as to render the deductions of little value.

* A very interesting discussion of these variations by Lieut. E. M. Weaver, U. S. A., appeared in the October, 1893, number of the Journal of the United States Artillery.

Has numerous bending cracks confined to the face hardened surface, 1″ to 1.25″ deep and .03″ to .1″ wide. None were extended or deepened by impact.

No. 312a.—Showing projectile. Test of Midvale-Holtzer 10-in. A. P. Shell No. 160, against Oregon's 17-in. Harveyed nickel steel barbette plate B-107, group 15, Carnegie Steel Co. Impact No. 6; striking velocity, 1983 f.-s.; striking energy 13646 ft.-tons; penetration 12⅜″; rebounded badly set up, twisted, scored, fuzed, chipped, and out of axis in the ogive. Shell increased in diameter at bourrelet to 12″; shortened 6.06″.

N. P. G. letter No. 697, Sept. 14, 1894.

No. 311a.—Showing projectile. Test of Midvale-Holtzer 10-in. A. P. shell No. 262 against Oregon's 17-in. Harveyed nickel steel barbette plate B-107, group 15, Carnegie Steel Co., made Sept. 15, 1894. Impact No. 5; striking velocity, 1983 f.-s.; striking energy, 13636 ft.-tons; penetration 30″. Back bulge star cracked. Shell rebounded entire, chipped and cracked around ogive's surface, and increased in diameter at bourrelet to 10.87″; shortened 1.8.″

N. P. G. letter No. 697, Sept. 14, 1894.

They become even still more unreliable in considering hard faced armor where the chemical composition is irregular, and the physical characteristics vary from the hardest chill on the surface to wrought iron-like softness at the back.

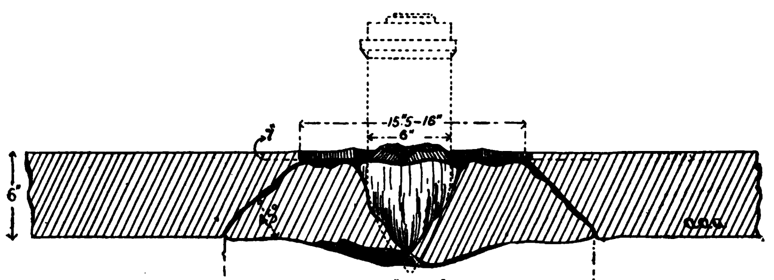
Variations in quality of armor-piercing shell, even of standard make, may occasionally be expected; that still greater ones are contained in the larger and cruder armor plates is equally true, so that when the two are about evenly matched, it is difficult to determine within narrow limits what is a normal result. The resistance of such plates cannot, even with the present comparatively simple condition of the art of face-hardening, be made a subject of calculation; and different applications of the processes of cementation and hardening, so little understood at present, may render the subject much more complex in the future.

The popular impression is that face-hardened armor resists the projectile by crushing it from the point; this rarely occurs, except in the case of very inferior projectiles, which go to pieces like a Prince Rupert's drop upon the point being crushed; or, in the case of soft shells, the point upsets and the head expands into a mushroom (see photos 315 and 326*a*). Many good projectiles retain sound and nearly perfect ogives, two-thirds way from point to bourrelet, after having forced the head into a plate (see photos 53, 91 and 311*a*). Others have the point rubbed off and the sides of the ogival abraded, scored, and twisted (see photos 310, 312*a*, 314*a* and 325*a*), but in none of these cases does the destruction of the shell start from the point. In nearly every instance, the failure of the projectile is along a conical shearing plane inclined about 45° to the axis of the shell with its apex at the center from which the head of the chamber is described. This is due to the unsupported walls of the shell splitting longitudinally and sliding over the head which has been arrested by the plate. An instance of this is shown in the excellent Texas side armor plate from Bethlehem; a fragment of the wall of the shell is embedded in the plate by the side of the ogival. (Fig. *A*.) It will also be seen in the same figure that the crater surrounding the shot, usually ascribed to the impact of fragments of the body and base, is often nothing more than the flaking or prying off of wedge-shaped fragments of the brittle surface.

Certain of the concentric cracks seen around impacts are due to

the blows of the walls of the shell, the upset and fused ends of which bear witness to their behavior. Others again are due to the cracking of the brittle surface upon the plate being "dished." These cracks have been noticed in many compound plates; even Grüson armor has shown them. There is the greatest difference, however, between the behavior of thick and thin plates in this respect, the former, as a rule of hammered or pressed steel, attacked by calibers but slightly exceeding two-thirds of their thickness, but which nevertheless averaged over one-eighth of the width of the plates; the latter, of rolled steel, attacked by calibers equal or even one-third greater than their thickness, and which rarely exceeded one-twelfth the width of the plate. In thick plates, the impact is usually surrounded by a shallow crater formed by displaced wedge-shaped chips of the brittle surface, and from that short radial cracks extend. The backs would seem less equal to the task of holding the mass together than in the case of thin plates, for cracking is far more frequent.

In the thin plates, there is usually considerable flaking of a nearly uniform depth about the impact. The surface of this flaking, and especially the fracture at its edges, is concoidal, appearing to follow a wave form originating at the impact. A remarkable peculiarity of every impact noted on good, thin, rolled, face hardened plates



SECTION OF AN IMPACT, PLATE NEARLY MATCHED.*

is the similarity in shape and proportional dimensions of the fragment broken from the plate.

* These dimensions were taken from a curved plate. In flat plates the angle is nearer 35° than 45°, which would indicate that, with regard to the backing, the resistance of a curved face hardened plate to normal impact is slightly less than that of a flat plate.

No. 336.—Test of experimental 6″ Wheeler-Sterling A. P. shell with soft metal cap, against 6″ face hardened nickel steel curved plate A—883, Carnegie Steel Co. Impact No. 10. Striking velocity, 1700 f.-s.; striking energy, 2006 ft.-tons; projectile penetrated plate, and 3 feet oak backing; recovered with portion of point broken off, and cracked. Shell shown in front of plate.

Impact No. 5 = 6″,	Wheeler special,	. . .	100 lbs.,	at 1800	ft.-s.,	penet. 3.2″.
" " 6 = 6″,	"	magnetized,	"	" 1900	"	" 4″.
" " 7 = 6″,	"		"	" 2000	"	" 3.6″.
" " 8 = 6″.	"		"	" 2100	"	" 4.4″.
" " 9 = 6″,	"	capped,	104 lbs,	" 1900	"	through all.
" " 10 = 6″,	"	"	105 lbs.,	" 1700	"	"

No. 265.—Further experimental test of 6-in. curved face hardened steel plate A—883, Carnegie Steel Co., which had been rejected on account of surface cracks. Carpenter 6-in. A. P. projectile, lot 2; striking velocity, 2000 ft.-s.; striking energy, 2776 ft.-tons. Line of fire normal. Estimated penetration about 4½″. Projectile broke up. This impact marked No. 4, N. P. G., letter No. 382, May 25, 1894. Plate unbacked.

Impact No. 1 = 6″;	100 lbs.	at 1800	ft.-s.	penetration	= 3.2″ (shown below No. 4).
" " 2 = 6″;	"	" 1800	"	"	= 2.4″ (shown to right).
" " 3 = 6″;	"	" 2000	"	"	= 4″ (shown below No. 2).
" " 4 = 6″;	"	" 2000	"	"	= 4.5″.

In the sketch showing a section of a 6″ plate attacked by a 6″ projectile, it will be seen that the face has scaled over a diameter of 15.5″; the frustum of a cone starts from this edge of the sound surface, curving down quickly into the slope of a 90° cone. There may be several concentric cracks around the impact, and each one will be found to be the origin of a similar conical surface. These conical back bulges can be initiated with comparatively light

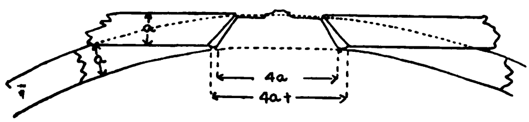


FIGURE SHOWING ROUGHLY THE COMPARATIVE AREAS OF BACKING SUPPORTING BACK BULGES OF CURVED AND FLAT PLATES.

blows, yet possessing the same general dimensions and shape as with the severest impacts, only in the latter case the frustum may be completely detached. Perforation, however, would occur by the projectile's head breaking out a small fragment directly opposed to it. A somewhat similar behavior is seen in the case of the third 4″ impact on the 3″ plate, No. 4.

Similar bulb-like foliations or sheathes may be seen in the cases of plates 935, 3″; 883, 6″; 874, 6″, and in the accompanying

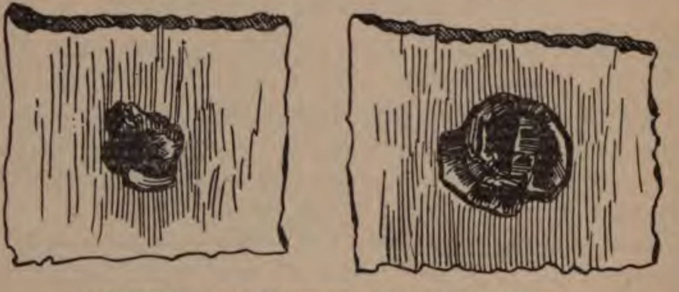
KRUPP'S 10.25″ NIS, GAS HARDENED.
Attacked by Krupp 112-lb. A. P. shell at 2160 ft. s., 12.2″ penetration.
Showing sheathes and rear cone.

sketch of Krupp's gas hardened 10.25″ nickel steel plate. The impact shown is that of a 112-lb. projectile moving at 2160 ft. s.

velocity. The plate was nearly matched, the perforation being 12.2″.

In plates where the body and back is hard and rather brittle, as in many of the earlier all steel face hardened plates, this peculiar effect is not produced. Projectiles inferior to the plate crush and chip away a crater in its face in which the ogival is welded. Projectiles superior to the plate either crack it apart or break a rough-shaped cylinder out of it, much as in the case of hard and very tough homogeneous steel alloy plates. (See sketch of Hadfield's 5-inch manganese steel plate.) Thin face hardened plates usually fail in this manner when perforated by undeformed projectiles.

FRONT BACK.



HADFIELD 5-INCH MANGANESE STEEL, HARDENED.
6″ Holtzer at 1400 ft. s.

The question may be asked, If the plate is going to fracture under the blow, why must it give way over an area of from 16″ to 24″ in diameter, when one of from 6″ to 14″ would have sufficed to allow the projectile to pass? The reason must be that the projectile's head, forced in as it is, acts as the keystone of an arch exerting pressure in every direction normal to its ogival. At some points, located on a circle about 16″ in diameter, the opposition to that pressure by the rigidity of the surrounding plate, supported and stiffened by its hardened face, is sufficient to shear the two apart. It is evident, however, that the resistance to the advance of the projectile is far greater than the energy required to punch out a hole about three times its diameter; that is, a peculiar resistance is experienced by the shell. In some instances the shattered ogival appears welded to the plate; more commonly, however, an extremely hard shell head is squeezed, scored and

ridged by the fragments of the hard surface carried in by it. Hence it is that so much assistance is lent the shell by a soft cap forced into the plate with and around it, and to a certain extent sheathing the hole and protecting the shell. This seems at least very plausible, as when capped shell perforate the plate there usually appears to be no cone formed. The plate, however, is dished in the vicinity of the hole perhaps 0.5″, at any rate far more than in the case of a non-perforating shell, which still may have badly racked a considerable area. The advantage of a rigid backing in the cases illustrated by this figure are apparent. Some doubt may be felt of the value of the ogival head, however, in such cases. The plate having broken along the sides of the cone, the energy expended in forcing the ogival into the plate must, in a measure, have been wasted. It would seem that a similar but much smaller cone would have been broken out by a flat-headed projectile, in which case all the energy would be concentrated on the area opposing the projectile. This, in fact, is probably one of the effects of the cap. It is interesting to note in this connection that in a trial of Grüson chilled iron armor with flat-headed and pointed projectiles in 1885 the mean penetration of the former was 1.935″, and of the latter only 0.459″.

The total energy of a rapidly moving projectile at the instant of impact has been expressed in two ways, as the effect expected is that of penetration or racking. In the first case, the tons of energy per inch of circumference gives the relative punching effect very accurately in soft, thin plates, provided the projectile is not deformed. In the second, the tons of energy per ton of plate gives relatively the amount of energy a hard plate is required to absorb. It is evident that the important questions of location of impact, projectile and plate deformation, and transformation of energy into heat, are here out of consideration. Actually beyond a certain point for each combination of energy, thickness and quality of plate, and rigidity of structure, the mere increase in weight has nothing whatever to do with the plate's resistance.

The limited dimensions of armor plates and the occasional location of impacts near the edges qualify the results, whatever theory is advanced; still, the principles developed in the attack of the central region of a plate of indefinite size are fundamental and something may be gained from their consideration.

The comparison of tons of energy delivered per ton of plate is obviously always unfair to the plate, unless it be in each case absolutely homogeneous and symmetrically disposed and supported around a normal impact. In addition, to obtain the comparative racking effect pure and simple, the expenditures of energy in penetration and deformation must be the same.

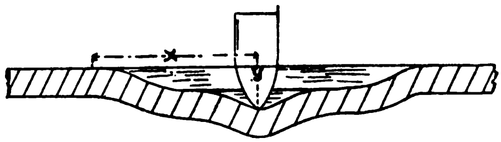
On the other hand, the energy per inch of cross-section of shot, especially with different calibers, gives no reliable comparison, unless the shots strike normally, escape deformation, and each inch of their sections do equal amounts of work. This is evidently impossible except in a disk-shaped projectile of molecular thinness. If, however, we regard the impact of projectile upon the center of a face hardened plate as the arrival of a succession of thin disks held in elastic relation to each other by intermolecular forces, perhaps the mutual reactions of such a plate and shell may be better understood.

A soft plate, the behavior of which is better known, if struck by a punch, stretches before it and tears away circumferentially, a disk being forced ahead while the elongated fibres forming the walls of the cavity are pushed aside and compressed into the body of the plate until the displaced metal crowds the surfaces adjacent to the impact up into front and back bulges. The diameter of these is chiefly influenced by the elastic strength of the metal and their height by its softness or ductility. That is, in the case of metal having a high elastic limit and hence lying near the failing point, a flow of metal started by pressure at the impact would be accompanied by a comparatively slight movement of the metal over a considerable area. In a metal having a low elastic limit the volume displaced is equal, but the movement under the same circumstances would be local. Probably a very fair comparison of the toughness of two plates would be the cotangents of the angles of their bulges under similar penetrations. If the metal lacks ductility, the great difference in displacement of adjacent particles must be accompanied by its rupture, the fringe flakes off or even a crater may be formed.

Let the behavior of a homogeneous oil tempered plate be considered, when subjected to pressures under the elastic limit. The punch depresses the hard and elastic surface immediately in front of it a distance y, the radius of the base of the depression thus formed

being x. Considering that the figure is approximately a cone, the extension of the elements would be $\sqrt{x^2 + y^2} - x$. The extension of the metal will, however, be extremely small even when it has a high elastic limit, in which case x will have considerable length.

This subject has been touched upon by a number of physicists in the investigation of the absolute measurement of hardness;



The y ordinates are greatly exaggerated.

with this difference, however, that, in the determinations of hardness, uniformly slowly applied pressures were alone considered, so that no wave movement due to the inertia of the material resisting a rapidly extending stress, as shown in the exaggerated sketch above, could occur. A most interesting memoir on the subject, by F. Auerbach, translated from the German by Carl Barus, may be found in the Smithsonian Report for 1891. Auerbach's experiments were founded on a theory by Hertz "that, if a sphere be pressed upon a plane so as to produce a surface instead of a mere point of contact, the impressed area would increase, within the elastic limit, as the two-thirds power of the total pressure, it will also increase as the two-thirds power of the radius of the sphere."

It was found that the hardness increased with the curvature of the sphere or lens; that is, although both lens and plate be cut from the same material, rupture will always occur in the latter, the former remaining intact. He calls attention to the analogy between the increased resistance of the convex lens and the surface tension of liquids. With that significance, the behavior of the lens and plate would resemble that of a truss and simple beam respectively. The metal of which a projectile is composed may be made at least as hard and certainly of superior quality to that of the surface of a face hardened plate. There is no reason, apparently, why the superficial film of the latter should not be ruptured under pressure, therefore, before the point of the former. The support of the underlying layers, though they add to the resistance

of the outermost one, do not increase its hardness. Upon impact the point of the projectile receives a concentrated support, as it were, from the better placed layers behind it crowding forward. There is no reason at all, therefore, why a sound and properly made projectile of *better material than the plate* should break up from the point. To do so, as Captain Tresidder has said in a recent article entitled "Notes on Armor Plates and their Behavior under Fire" (Occasional Paper No. 7 of the Royal Engineers), the disintegration of the projectile must commence the instant the point strikes the plate, but that will hardly occur even with the most inferior projectiles, unless the superficial resistance of the plate far exceeds their energy of impact. The deductions of Captain Tresidder appear to be drawn from data which he has seen fit to withhold, they are so widely different, however, from experience obtained in this country, that advantage is taken of this opportunity to comment upon them; not for criticism's sake, but to draw out views, if existent, not apparent to the writer.

To be just, Captain Tresidder's paper was written in 1893, it was published, however, with a few modifications, in October, 1894. His theory of the smashing of the projectile upon a face hardened plate is that of pulverization on impact progressively from the point; this is in keeping with his statement that the action of the soft iron cap employed on certain experimental projectiles is to support the point laterally, so that the initial splitting cannot be done without bursting the cap, as "pulverization must be initiated before penetration or it will not occur at all."

A multitude of parallel, conical, shearing planes are supposed to form in the projectile from the point (which becomes in consequence a spindle, towards the base) by the arrest first of the point, then successively the sheared conoidal segments which split over the point and the other segments gone before. This breaks the shell into a myriad of fragments, which are then mashed together in the indent. Though how there can be an indent if the shell is pulverized and has its energy divided among minute fragments is inexplicable. The whole theory is, in fact, inexplicable even though confining its application to chilled iron projectiles.

If an inferior projectile, or for that matter a fairly good one, be fired against a very superior face hardened plate at too low a velocity to penetrate, its energy may be sufficient to cause it to

No. 258.—Experimental test of 6.-in. curved face hardened nickel steel plate A—883, group 13, Carnegie Steel Co., which had been rejected on account of surface cracks. Photograph showing method of securing plate at the two ends without backing.

No. 325a.—Test of Carpenter 10-in. special forged steel A. P. shell No. 15 against Massachusetts' 17-in. face hardened nickel steel barbette plate No. 5523, B. I. Co., group 15. Impact No. 5 showing shell; striking velocity, 1930 f.-s.

No. 335a.—Test of experimental Wheeler-Sterling 6-in. A. P. shell with soft steel cap on point against 6″ face hardened nickel steel plate No. 883, Carnegie Steel Co. Impact No. 9: striking velocity, 1900 f.-s.; striking energy, 2506 ft.-tons; line of fire normal. Photograph of projectile after recovery.

fly to fragments, hardly leaving a mark on the plate. This seems to bear out Captain Tresidder's theory and contradict that advanced with regard to the relative hardness of a sphere and a plate. The latter did not contemplate *impact*, however, or for that matter still less, *impact with insufficient energy to penetrate.* This stoppage of the projectile on the surface of the plate would correspond in its effect to a much greater energy distributed over a greater distance, only in the latter case the head of the projectile, having penetrated, would be supported by the surrounding metal.

With higher velocities, however, good projectiles will penetrate until the resistance has increased sufficiently to counterbalance or nearly counterbalance their remaining energy, when the shell, being stopped, is much in the same condition as the projectile fired at an impenetrable plate with that remaining energy. The result is that, as a rule, the unsupported part of the projectile splits and shears over the head gripped in the plate.

What the face hardened plate does is merely to present so great and concentrated a resistance to the projectile's advance at some one instant in the impact *as to stop it*; disintegration follows as a matter of course.

The loosely worded explanation that face hardened plates stop the projectile by breaking it up and distributing its energy, puts the cart before the horse, the effect is confused with the cause. A broken projectile or some of its fragments may get through a plate, but if it does, these fragments have acted together as a unit; the projectile cannot have been wholly crushed though the entire resistance of the plate has been expended in breaking it up.

In connection with the above, the following tests may be interesting. The plate was the Brooklyn's 3-inch Carnegie face hardened nickel steel ballistic plate. The projectiles were of service 4-inch Wheeler-Sterling type, with and without caps. They were of good and uniform quality and composition.

See accompanying photo.

No. of impact.	Projectile.			Result.	
	Kind.	Weight in lbs.	Velocity ft. s.	Projectile.	Plate.
5	Capped.	34	*600	Smashed.	Impacts 5, 6, 7 and 8, upon same spot. Saucer-shaped depression 1/8'' deep.
6	"	35.5	*600	"	" " " 1/8'' "
7	Service.	32.5	600	"	" " " 1/8'' "
1	"	33	1206	"	Penetrated 0.5'', plate dished 0.3''.
2	"	33	1357	"	" 0.5'' " " 0.4''.
11	"	32.5	1600	Head into backing, body smashed.	Some flaking, concentric back cones started.
10	Capped.	35.5	*1600	Through all into butt, in three pieces. Point scored and abraded.	No sign of back cones, back bulge cylindrical, punctured out in shape of head.
9	Service.	32.5	1700	Through all into butt, in two pieces. Point smooth and unhurt.	Slight flaking, no appearance of a conical back bulge. [Undoubtedly a superior projectile.]
8	Capped.	34.5	*1700	Through all whole, uncracked. Point scored and ridged.	Considerable flaking.
4	"	35	*1700	Through all, broken in several pieces. Point scored and ridged.	Some flaking. Back cone initiated.
3	Service.	33	1800	Body smashed, head fast in back cone.	Entrance 6.25'' in diameter, back cone separated 0.5'', but held up by the backing.
				*The velocities were estimated for 33-lb. projectiles. Those given for heavier ones are therefore slightly too great.	The white chalk marks on the plate are concentric cracks formed during the test.

There is much to be learned from these tests, even allowing for a certain variation in the plate from point to point, although the impacts were closely grouped, and allowing for a still greater variation in the separately cast, forged, and treated projectiles; the latter differences being perhaps further accentuated by variations in velocity, angle of impact, etc.

It appears from the above that an energy incapable of affecting the plate may still destroy the projectile; also that the plate may exert sufficient resistance to break up the shell without destroying its point, and finally that the cap does *not* support the point against splitting, but rather eases both plate and projectile under impact.

It may now be asked, Of what use is hardness on the surface if it does not serve to crush the point of the projectile? The answer is that the more rigid the surface, the more certain that the energy of impact will be widely distributed while the resistance of the entire thickness of the plate is brought to bear against the advance of the projectile, as the displaced metal can only flow to the rear. At the same time, when penetration is effected the projectile carries

No. 249.—Experimental test of 6-in. nickel steel face hardened plate A—874, *without backing*, Carnegie Steel Co. 6-in. Carpenter projectile; striking velocity, 1800 f.-s.; striking energy, 2249 ft.-tons; projectile broke up, head welding into plate. Back bulge forced out 1¾″ and star cracked. This impact marked No. 7. N. P. G., letter No. 354, April 25, 1894.

Impact No. 6 = 6″, 100 lbs., at 2000 ft.-s., 2776 ft.-tons.
" " 7 = 6″, " " 1800 " 2249 "
" " 5 = 8″, 250 lbs., at 1472 " 3754 "

No. 334.—Test of experimental 4-in. Wheeler-Sterling A. P. shell No. 1268, with soft metal cap, against Brooklyn's 3-in. face hardened nickel steel side armor plate A—935, group 14, Carnegie Steel Co. Impact No. 4. Striking velocity, 1700 f.-s.; striking energy, 662 ft.-tons. Projectile penetrated plate, backing, and broke up, pieces being recovered about 18″ in the sand.

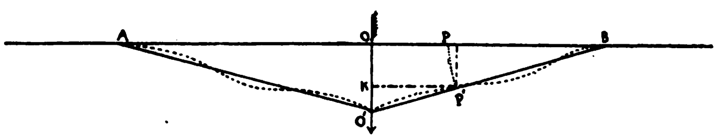
No. 350.—Test of Wheeler-Sterling 4-in. experimental A. P. shell No. 15, without cap, against Brooklyn's face hardened nickel steel side armor plate A—935; striking velocity, 1600 f.-s. Impact No 11. Shell penetrated about 6 inches, and broke up; point welded into back bulge.

Impact No 1 = 4″, 33 lbs., at 1206 ft.-s.
" " 2 = 4″, " " 1357 "
" " 3 = 4″, " " 1800 "
" " 4 = 4″, 35 lbs., " 1700 " (special capped).

with it a mass of jagged, untractable fragments which greatly impede its advance.

A very important accompaniment of hardness is elasticity, which increases, however, much more rapidly than the hardness does. It is, of course, of special value under impact, permitting a greater depth of plate to aid the surface.

Now, the velocity with which the pressure increment at any instant is transmitted over the stiffly elastic surface is far greater than that of the advance of the projectile, so much so in fact that the assumption is not difficult, that the depression is due to the position of the advancing shell at the same instant rather than its position an instant before.



Let AB represent the original plane of the surface of a thin plate, and O', P', the position of points O and P when the surface is depressed to its elastic limit by a force acting along OO'. The correct shape of the depression is represented by the dotted line. The radius of the circle on which any point P is located has been increased from OP to KP', and this circle is therefore in a state of tension. Had the element OB, in being pressed down into the position $O'B$ extended equally over equal distances, the depression would be a true cone, every point of which would be subjected to equal circumferential and elemental tensions, while the base AB would be indefinite in extent. Such a condition would only result when the elastic limit was zero. It is apparent that the stress transmitted through any unit length of a concentric zone or circle, such as that passing through P', must be inversely proportional to the radius KP'. In the same manner the extension of that unit, under the elastic limit, will be inversely proportional to KP'. In fact, the depression will be of the character of a semi-cubic parabola.

Now, if the pressure is increased above the elastic limit, the metal, if ductile, near the center O' would elongate rapidly, allowing the shell to advance, carrying the metal down before it; this

action would result in the plate being left dished and without a fringe, as in fact is the case when a comparatively thin plate is attacked by a large caliber projectile.

In the case of a thicker plate or a smaller caliber for the same plate, however, the case is different. The initial tears, before the point, release both radial and circumferential tensions, the points of the sectors thus formed draw back and the maximum tension is carried to a zone outside that which has just failed, extending the radial cracks and permitting the point to advance and attack a second layer in a similar manner. The free points of the sectors are then forced out of the way in the direction of least resistance, curling up about thé point foiming the "fringe." There appears to be a great regularity in the number and position of radial cracks or tears as shown on the back bulges of wrought iron and simple steel plates, as well as in the front bulge and fringe of steel plates. Doubtless the location of the first crack formed in the highest stretched zone of a fairly uniform metal is at its least ductile and strongest point. To permit this zone to stretch on one side more than the other would require a side movement of the shell, or the metal to flow around it, becoming attenuated on the ductile or cracked side and banking up on the other. The zone, barring such a side movement of the shell or, owing to the very small time limit, improbable flow of metal, must stretch equally in sensibly equal distances; the hardest and least extensible portions would therefore be the locations of the initial tears which would also be spaced quite uniformly about it. This explains why the direction and location of the tears in wrought iron plates seem so little affected by the fibre; also why on occasion a whole section of fringe or bulge will be broken out through its failure to extend.

The length of the cracks would undoubtedly be a function of the elastic strength of the plate. Thus, the point of a shot having opened a stiffly elastic plate starting radiating cracks, the more the points submit to bending, the more distant zones would be subjected to stretching beyond their elastic limit continuing these cracks. At the same time, the surfaces of the points being stretched radially more than the metal beneath, concentric cracks might also be initiated.

After the point has passed the surface, the latter is held down

by its cohesion to the intact stratum of metal added to the friction of the shell on the walls of the opening, but resists with all the elastic strength of a layer of metal increasing in thickness as the shell advances. Should, now, the advancing plane of greatest stress pass through a weak spot, or should the accumulating elastic strength of the front part become equal to the undertaking, it will pull away and a circular lamellation be formed which will practically serve, so far as the point is concerned, as the face of a new plate.

It is evident, that in the passage of a shot through a plate, the formation of every lamellation is accompanied by the liberation of an amount of energy in the projectile necessary to bind down the preceding stratum of the plate, and which is also indicated by the tearing away of the reacting face, or by an apparent accession of energy in less elastic plates by breaking out the back bulge. The toughest plate is undoubtedly the one in which there are numerous incipient and no developed lamellations of this sort, for their entire absence would only occur in an extremely soft and weak plate, or an extremely hard and brittle one.

Consider now a thin, rolled, face hardened plate having a soft but tough back. The hard, thin surface being very stiff and elastic, the cone of depression will be wide spread, shallow, and supported by the back over a considerable area. Should it crack radially, as it must do quickly under stress, it is still held together or bridged by the back, thus permitting still further bending and extension of the supporting area before penetration; this again leads to a further extension of the radial cracks and stretching along them of the back. The stiffer the combination of face and back, the greater the area of the plate supporting the impact. The appearance of concentric cracks in the face indicates that the hard face is too thin or the stiffness of the back is insufficient. Had the back been weak and the hard face thick, the brittle behavior of the latter would have characterized the impact. Such concentric cracks are seen in the photo of the 3″ side armor of the Brooklyn. If the hard face had been too thin or soft, a front bulge might be formed as well as a fringe which would flake off. If the hard face was thicker and the back gradually less hard and strong, the best effect would be produced. By the time the surface layer had been bent to the point of cracking, the metal beneath

would have communicated the stress though a greater and greater area as it was transmitted to the back of the plate.

Thus far the hardened surface, where it has not been shattered or flaked off, has bound the metal below it together, preventing its extension. And this is the true object of the hardened surface; not, as seems so commonly supposed, to, of itself, shatter the projectile, the soft back being merely to hold its fragments in position, as in compound armor. The hard surface and the metal immediately below it have for their duty the prevention of all forward and lateral displacement of the metal beneath. This would be difficult enough, anyway, on account of its own rigidity, but the assistance it has demanded from the hard face is frequently seen in the latter's extensive flaking. There being no front bulge nor fringe, the metal before the projectile is carried in, gripped between it and the surrounding walls. It still binds the softer metal together, causing the entire thickness of the plate to resist as a unit, even though being incapable of flow, it is ground to fragments, which in turn score, fuse, and abrade away the surface of the ogival of the projectile.

The enormous increase of resistance in face hardened armor is brought about in this manner, not simply because it is more difficult to force the point of the projectile through the inch of hardened steel face. It is evident that, while a certain thickness of hard face is necessary to secure the best results, if it readily flakes or shears away from the metal beneath, a point is quickly reached beyond which its increased thickness is of no particular advantage, as it would fly to pieces immediately upon being struck. If this hard face is, however, carried into the back a slight distance in a series of small gashes or pockets, its stiffness would not only be greatly increased but shearing or flaking prevented by the hooks or protuberances extending into the softer metal. At the same time the advantage of a thicker hardened layer would be obtained without detracting from the elasticity and toughness of the body of the plate.

When a soft plate brings an undeformable projectile to rest it is done gradually, and if the plate offers no sudden change in its resistance as the projectile penetrates, it must have regained a position of equilibrium when the latter finally stops. The structure may have moved, bolts snapped and the plate been set back,

still the reaction is directly opposed and equal to the action so long as it continues. In the case of the rebound or disintegration of the projectile, the case is different. The balance of forces is suddenly destroyed, leaving a large amount of unbalanced energy in the plate which must vibrate as a bell under the blow of a hammer. The bolts and fastenings of face hardened armor should therefore be of the toughest, most elastic quality, though not necessarily, in thin plates at least, more numerous than in the case of softer armor. An important consideration in this connection is the peculiar weakness of non-homogeneous armor to vibration. If the method of resistance contemplates the destruction of the projectile, then vibration must ensue, and the tendency of these vibrations to be uniform in amplitude and velocity at equal distances from the impact requires equal duty of strong and weak parts; the same play of those elastic and free to move as those bound down by bolts or otherwise stiff and brittle. Now, the amplitude of these vibrations are a function of the elasticity of the plate in the vicinity of the impact, and though it diminishes as it recedes, a less elastic portion of the plate called upon to vibrate to this extent may be unable to respond and will crack. Thus isolated cracks are sometimes formed at distant points, and in one instance (see figure showing 4″ Brooklyn barbette) repeated impacts on one end of a plate shook off the other and unsupported end. Similar occurrences have been noted in compound plates.

The amplitude of vibration on the surface exceeds that on the back by nearly the amount of elastic compression and extension of the thickness of the metal. To make it clear, we may suppose the plate made up of thin flexible sheets of steel separated by layers of rubber, when the actual movement of the last or back sheet would be less than that of the face by the compression of the rubber between; and this would be less and less for each layer, as the force transmitted was distributed and expended in the compression. Now, if one of the steel sheets should be replaced by a thicker and stiffer or less elastic one, the vibrations of the latter through having less amplitude must cause not only a shearing stress along its face, but a considerably greater tension there on the rebound than exists at any other plane. Hence, as would naturally be the case when this unyielding stratum occurs at the junction of the layers of a compound plate of which the

face has great elasticity, and the back, lead-like, tends to retain the shape of the hollow of the initial wave, the face is apt to tear itself away when it takes the form of the crest. This is the serious objection to compound armor, and in fact, to all hard faced armor in which the face, while preserving its continuity over large areas, differs in a marked and abrupt manner in elasticity from the metal beneath. (See photos 259 and 265, plate *A*883, showing flaking.)

The photograph of plate *A*883 shows how considerable flaking may occur in even a most excellent plate where a superficicial, continuous, and very hard chilled face is supported on a tough but extensible back. Many methods have been devised for overcoming flaking of this sort in compound armor as well as preventing the extension of deeper cracks. In 1877, Whitworth set hard steel plugs, intended to break up the projectiles and to prevent the extension of cracks, in a soft steel plate. Later he applied the same principle to other plates by covering the armor with small plates of hard steel, intimating that the best way to limit the cracks in steel wou'd be to "manufacture" them. In 1883, Whitworth is quoted as saying, "that an armor plate of compressed steel, built up in segments in such a manner as to prevent the extension of a crack or split beyond the limits of the segment in which it was produced, would suffice not only to resist but break up any projectile of an ordinary character." In 1878, a Cammell-Wilson patent proposed to localize cracks by soldering plates to the face of the armor. In the same year, Ellis patented the introduction of wrought iron bars in the surface of compound plates for the purpose of reducing the lengths of cracks in the steel when perforated by shot. A far simpler, if not more efficacious, method than any of these would be merely to gash or score the hard film on the face hardened plate. These gashes, pockets or corrugations would also serve not only for the more expeditious and better controlled cementation, but would permit deeper chilling in hardening; the surface would be more rigid, less inclined to flake, and shearing away from the soft back would be prevented.

That such gashes or openings forming breaks in the continuity of the hard surface do not detract from the plate's resistance is evident, as on account of the rigidity and brittleness of the surface the whole support of the back of the plate cannot be felt until the

No. 323.—Ballistic test of Brooklyn's 4-in. curved face hardened nickel steel plate A—958½, group 16, Carnegie Steel Co. Top end to the left. Impact No. 2. Carpenter 4-in. A. P. shell, No. 1492, lot 5; striking velocity, 1595 f.-s. (specification velocity for 24'' backing); striking energy, 583 ft.-tons. Impact in a group of horizontal surface cracks ⅜'' to ⅝'' deep, below soft strip. Shell smashed on plate, probable penetration 1''. Plate irregularly scaled around impact, scaling confined to old cracks. Surface cracks not developed; no new ones started.

Board report, N. P. G., letter No. 740, October 10, 1894.

No. 332.—Ballistic test of Brooklyn's 4-in curved face hardened nickel steel plate A—958½, group 16, Carnegie Steel Co. Top end to the left. Impact No. 8. Carpenter 4-in. A. P. shell No. 120 (no lot); striking velocity, 2000 f.-s.; striking energy, 916 ft.-tons; penetrated the plate and about 20'' of backing, breaking up. Ogive remained in backing, remainder flying out of shot hole. The right hand edge of the plate 16'' wide thrown to the ground, from the place where cracked in previous round. A new surface crack 10'' long developed to the right of No. 8. Shot hole 4¼'' to 5'' in diameter.

Board report, N. P. G., letter No. 740, Oct. 10, 1894.

No. 1 = 4'',	33 lbs.,	at 1491 ft.-s.	Into wood 12''.
" 2 = 4'',	"	" 1595 "	Penet. 1.6''.
" 3 = 4'',	"	" 1676 "	Through all.
" 4 = 4'',	"	" 1595 "	Penet. 0.9''.
" 5 = 4'',	"	" 1595 "	Penet. 1''.
" 6 = 4'',	"	" 1595 "	Penet. 1.5''.
" 7 = 4'',	"	" 1595 "	Penet. 1''.
" 8 = 4'',	"	" 2000 "	Into wood 20''.

former is extended, and hence broken. Numerous tests have been made of face hardened plates in which cracks from 0.5″ to 0.8″ deep, some as wide as 0.12″, were formed in bending the plates after cementation and before hardening. The range of temperature in which the highly carburized surface could bend without rupture being far less than in the case of the plate's back. (Several examples of plates showing cracks of this description are given.)

The chill cracks confined to the surface of certain Grüson armor plates have been tested in a most thorough manner with results similar to those obtained in the case of face hardened armor. That is, they seemed in no way whatever to weaken the plates; no cracks were initiated by them, nor did they give direction or extension to any of the fresh cracks formed by impact.

It may, of course, be asked: If it is an advantage to extend the stress of the blow over as large an area as possible by causing the depression to be wide and shallow, would not that result be prevented by cutting the surface up into small sections which would tend to localize the bending effect by shortening the arm? In reply, it may be stated that in stiff hard faced plates attacked by comparatively small calibers, the depression is so shallow that radial cracks seldom extend beyond what would be the position of the fringe in a soft plate. Also that in more elastic hard faced plates, or stiff plates attacked by large calibers, the angle of the cone is such that the brittle surface is unable to adapt itself to it in the immediate vicinity of the impact, so that both radial and concentric cracks are formed, causing flaking in no way affecting the integrity of the tough and elastic metal beneath.

Thus far, thin plates alone have been considered. In the case of thick plates, the typical failure is by cracking to an edge, then, perhaps, allowing perforation. There are a number of reasons why the thick plate is more liable to crack than the thin one. The metal displaced by the point of the projectile in thin plates crowds before it, causing a back bulge. In a thick plate there may be sufficient stiff body and back before the projectile's point to prevent this at first, forcing the metal aside about the ogival and either causing great fragments of the face to fly or splitting the plate. With the larger caliber the same slight penetration requires a much wider opening; the effect of the shell, so far as the layers

are concerned, is therefore local, being more concentrated and abrupt. The only way for thick plates to avoid cracking seems to be by failing locally; that is, by possessing a weak body and back, which of course may be carried too far.

In this connection, it would be well to consider the various causes from which plates crack under impact. 1. Initial stresses, flaws, or other defects. 2. Wedging apart of the plate. 3. By bending or breaking through on the giving way of the structure behind the impact.

In certain armor plates the first shot develops important cracks while those following have comparatively little effect. Thus in the 3″ face hardened nickel steel plate No. 4 (Fig. 60/91), the first

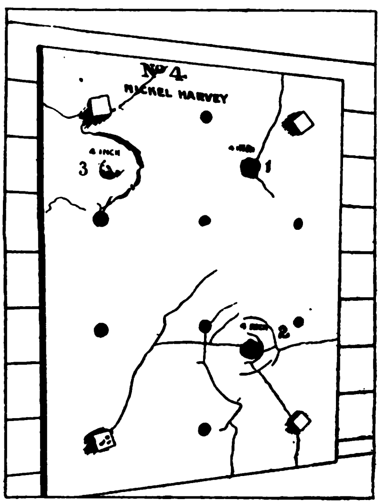


FIG. 60/91. 3-IN. PLATE NO. 4.
The impacts of the smaller projectiles are not shown.

6-pdr. shot caused a through crack from the impact at the center of the plate to the bolt hole at the left lower corner. At the same test, a 3″ all steel plate was cracked through by the first shot, after which repeated impacts produced no other cracks. Evidently these first cracks were entirely due to stresses in the plates caused by faulty tempering. These stresses being evolved by the plates cracking, subsequent impacts produce effects strictly proportional to their energies.

The so-called "wedging effect" of a projectile whose caliber is large compared with the thickness of the plate, is merely the result of a combination of the uniform radiating crack or tear before described, with lines of structural weakness due to existing stresses, defects in the metal, or the proximity of an edge or old impact. In this case one or more of the otherwise incipient radial cracks open out and render the extension of the rest unnecessary. The idea that cracks run to weak points is of course absurd, they follow the weakest lines which may or may not lead towards the nearest edge or weak spot. They may start from weak spots or lines of stress, however, independent of the impact, through vibration. If, however, as in the case of a large caliber projectile, the zone of metal stretched to its elastic limit, preceding that in which cracking has occurred, both being practically concentric and circular, widens as the projectile enters until it reaches an edge or defect, the plate snaps to that point. After this the entering shot acts as a true wedge to pry apart the plate with an effort concentrated perhaps on a part of the circumference of the shot hole as yet showing no weakness whatever. A good example of this is the cracking of the Schneider all steel plate in the armor trial of 1890 under the 8-inch impact.

The 3″ plate No. 4 labored under the disadvantage of having been cemented and hardened while containing twelve 2″ through bolt holes. Yet, after shattering twenty-one 6-pdr. armor-piercing projectiles at 1804 ft. s. velocity, it stopped three 4″ 36-lb. A. P. shell, moving at velocities of 1700 ft. s. The cracks in this plate do not appear at all due to the wedging effect of the projectiles. Thus the third shot has nearly broken a large conical fragment out of the plate without cracking to or from the impact. Another shot is surrounded by concentric cracks, showing the toughness and elasticity of its backing. It will be noted that in weak backed compound plates the radiating cracks from successive impacts often cross at all angles, apparently having no effect on each other. Another peculiarity in the case of the 3″ plate is that neither the 6-pdr. impacts nor the bolt holes appeared to determine the direction of the cracks, which in fact, in all but two instances, seemed to avoid the former. Two experimental face hardened plates (Fig. 224), on the faces of which were a number of tap bolt holes, behaved in a similar manner. There is

reason to believe that these plates were in a state of stress, however, and that the crack near the first impact, caused by the second shot, *started from the edge of the plate.* Cracks of this sort may generally be detected by their running by the side of the impact and not to it. Repeated impacts, of course, weaken these plates; large areas are caused to vibrate violently, and are perhaps extended or compressed, while original lines of weakness are accentuated by the natural accumulation of strains about the more sensitive points.

In considering the resistance of plates composed of layers of varying strength and elasticity, the problem is undoubtedly rendered more complicated, from a mathematical point of view, by regarding the plate as if made up of thin sheets separated by springs corresponding in strength and amplitude to the varying elasticities. Some light may be thrown on the subject, however, and the attempt will be made. In this case, the energy of the projectile should also be regarded as divided among a series of disks of molecular thickness separated by weightless springs whose play and strength correspond to the elastic compression and strength of the metal at the various points.

Should such a projectile strike a rigid, impenetrable target, the first disk delivers up its energy, which is transformed into heat, and the possible vibration or movement of the structure as a whole. It is probable that some energy is also stored in the elastic deformation of the molecules themselves. The second disk arrives with its energy diminished by that required to compress the spring before it; if there is sufficient left to overcome the molecular forces its particles may be forced over and among those of the first disk, the remainder of the energy going into heat or compressing the molecules themselves. Doubtless this transfer of energy is taking place at the same instant along a considerable length of the projectile, involving numerous disks and springs, and forming a wave of compression longer or shorter according to the strength or weakness of the springs and the velocity of the disks. The velocity of propagation of this wave determines the duration and character of the impact. A sudden stoppage of the leading members of such a system in which, through weakness of the springs, the wave of compression is very short, may cause it to be crushed in detail; crushing must occur anyway against such

a target when the disks contain more energy than the springs can absorb, or may be converted into heat in the crushing together of the molecules; for it is inconceivable that two particles stored with kinetic energy could exchange that for a state of rest at a higher temperature upon the first instant of an imperfect impact. If the compression of all the springs to the minimum elastic point, plus the heat imparted to plate, projectile and the surrounding atmosphere, as well as that expended in deforming the molecules themselves, did not consume all the energy, that remaining would be employed in forcing the particles in among each other, causing a displacement in the direction of the least resistance at right angles to the line of flight. The resultant force would create a shear plane at 45° to the line of flight. The compression of the springs or molecular forces is doubtless involved with that of the molecules themselves, it has been thought advisable, however, to consider them separately on account of the purely speculative nature of the latter.

The stiffer the springs, or the higher the elastic limit of the metal, the longer the wave of compression and the greater the number of disks acting together. With a low elastic limit, the projectile would be set up or crushed in detail. If its energy be entirely stored in the compression of its springs and dissipated in heat it will rebound, perhaps in fragments, through crushing on impact.

Suppose now that the target is composed of layers held apart by springs similar in character to the projectile. It is apparent that it will require considerable more energy to compress the first plate spring than that of the projectile, on account of the extensive supporting area. The latter will, therefore, where the two are nearly matched, be in a state of full compression some time before the plate; and it will then act as a unit upon the layers of the plate in detail, more or less marked according to the latter's elastic weakness and play of springs. In this way penetration of a homogeneous plate occurs; its resistance being necessarily expended more or less in detail.

If the exterior springs in the plate are extremely stiff and have very little play, as in face hardened armor, it is apparent that a much greater compression must be exerted upon the projectile with a very slight movement of the surface layers of the plate,

and if the latter's exterior is not yet wholly compressed when the projectile is, the remaining energy must be considerably diminished before penetration can occur.

In a theoretically perfect face hardened plate, the elastic limit of successive layers would be regularly lower, starting from the base of the chill and extending inward. As the extension or compression of each, within the elastic limit, would be proportional to the stress, and as the stress, being distributed over larger and larger areas, is less for each successive one, a point might be reached when every layer opposed to the advancing projectile is stretched to its elastic limit. The slightest further advance is, of course, met by a vastly increased resistance, the front layer of the plate possibly cracking and the others elongating. The projectile being fully compressed, any sudden increase in resistance will cause a more or less abrupt retardation, indicating a considerable loss of energy which, not being expended on the plate, must be done on the projectile.

It may be asked, Why would it not be better to have the entire plate of the high elastic strength of the face? If resistance to an instantaneous non-persistent impact was all that was required this might be the case, but something more is wanted, that is, the ability of the plate to hold together at least for a minute space of time. In metal of high elastic strength, the failing point is usually but little beyond the elastic limit; there is no broad range of permanent elongation before failure, so that a crack initiated at the surface would run through the plate with but a moderate increase of stress.

Recently a 6″ face hardened plate was perforated by 6″ projectiles of an improved type at a striking velocity of 1700 ft. s. The same plate had withstood service armor-piercing projectiles at a velocity of 2100 ft. s. This has led to the idea that, with still further improvement in projectiles, more resistance will be lost by the comparatively soft body and back of Harvey plates than will be gained by their hard face, so that a return to a homogeneous but a tougher type of plate probably of some nickel, chrome, or manganese steel alloy will be in order. This argument is fallacious. The body of Harvey plates, especially those of moderate thickness, are usually tougher than the old oil tempered

plates, having about the same elongation but often considerably greater tensile strength.

In addition, while protesting full faith in a rapid advance and development of the metallurgical arts, especially now that the capacity and application of the electrical furnace has been so greatly extended, the writer fails to see that the promised alloy has yet appeared above even the experimental horizon. As under the most favorable circumstances it required three years of experimentation before service face hardened armor was sufficiently developed to be contracted for in this country, and nearly a year more before the process had been demonstrated as practicable and a success, it does not appear that the new alloy, as yet unknown even to the laboratory, is a dangerous competitor. Even should it appear, it will doubtless be as susceptible to the various processes of face hardening as its weaker predecessors which have been thus benefited.

The objection to the homogeneous plate, whether water tempered or oil tempered, is that if tough rather than hard it resists in detail and through its own destruction almost as does wrought iron. If it is hard its elastic limit is near its failing point, it can stand one instantaneous impact, perhaps, but it cannot flow; there is no way of absorbing energy except in a weak fashion by cracking, and if the projectile is not destroyed perforation may ensue. It is therefore better, as the back of the plate is approached and a less and less demand made upon its elastic strength, to lower the elastic limit and increase the ductility. There is a limit to this, however, in thick plates. There is another point in this connection. Some authorities do not regard elongation as of much importance under impact; they point to the failures of car axles and mishandled boiler plates. These, despite the ductility shown in their test specimens, frequently appear, when fractured in service, sharp and even crystalline with no signs of ductility. Ductility cannot be shown unless the metal draws down. If a stress passes over a line of weakness of less resistance, as at the edge of a cooling plate, the opposing forces working on each particle in that line are balanced to the last. There does not appear to be, as in the case of a test specimen, a severe stress on the exterior and a less one on the interior, whereby the particles are given an oppor-

tunity to separate successively and flow in the direction of least resistance. Stress is applied to each individual particle, and the separation of a single pair means the separation of all.

One point more: until penetration occurs the cone of depression is intact; to resist the first penetrating effect therefore until the base of the cone is widespread is to greatly increase the resistance. The first effect of penetration in homogeneous plates is a distinct flow of metal. If that before the projectile refuses to become viscous under pressure and flow; if it lies there, for example, like granite, that may be pulverized but the particles of which will not slide over each other, an entirely new character is given the resistance of the surface of the plate. The point of the projectile must carry this intractible film before and around it. Every advance drags in more of the jagged fragments of the hardened surface, cutting and scoring ogival and plate as well, thus largely increasing the volume of metal which must be removed to permit the passage of the shot. There is a different thickness of this hard surface most suitable for every thickness of plate. Its object is to distribute the energy of the projectile; to prevent the flow of metal up and around it; to force down the plate surface and keep its resistance extended over as large an area as possible, as though bottled up and braced at the point of impact. Thus the absence of a front bulge must indicate that all of the resistance of the plate has radiated from the shot's head, and been widely distributed. The presence of a front bulge indicates a more local resistance, the displaced metal having simply eddied about the shot's head.

The idea has been expressed by some that the merest film of hardened surface is all that is necessary. This is incorrect. Service projectiles which have succeeded in piercing good face hardened plates, frequently have a considerable depth of the ogival surface fused and scraped off. As the head of the projectile enters there is opposed to each zone of the surface of the ogival the resistance of strata of varying hardness and elasticity, the largest at any one instant being that of the hardened surface. Should this be a mere film, its peculiar effect would be hardly appreciable, although the varying characteristics of the strata below would permit the plate to concentrate its resistance and give a good account of itself.

No. 239.—Impact No. 4. Test of 6-in curved face hardened nickel steel plate A—874, group 13, Carnegie Steel Co. Carpenter special 6-in. A P. shell, No. 925, lot 7. Striking velocity, 2110 f.-s. Shell much broken; penetrated plate entirely, lodging in backing. No cracks in plate. Hardened surface scaled around impact. N. P. G., letter No. 282, April 3, 1894.

See No. 243a, below, for other impacts.

No. 243a—Back of 6-in. face hardened nickel steel plate A—874, group 13, Carnegie Steel Co., showing the back bulges of 6-in. impacts Nos. 1, 2, 3 and 4, and 8-in. impact No. 5; the striking velocities being 1472 f.-s., 1659 f.-s., 1975 f.-s., and 2110 f.-s. for the 6-in., and 1472 f.-s for the 8-in. N. P. G., letter No. 314, April 13, 1894.

Impact No. 1 = 6″;	100 lbs.	at 1472 tt.-s.	= 1504	ft.-tons.
" " 2 = 6″;	"	" 1659 "	= 1910	"
" " 3 = 6″;	"	" 1975 "	= 2707	"
" " 4 = 6″;	"	" 2110 "	= 3090	"
" " 5 = 8″;	250 lbs.	" 1472 "	= 3754	"

It is found that when projectiles large in caliber compared with the thickness of a face hardened plate most nearly match it, the head enters until its bourrelet is clear of the intact hard surface when it breaks out a dome-shaped back bulge, to which its head remains welded, while the body and base are crushed and thrown to the front. In most cases, a few feet less velocity will make the difference between complete perforation and the bare clearance of the hard surface by the shoulder of the projectile. The crushing of the latter in such a case naturally takes place at the instant maximum resistance is offered; that is, when the crumbling, expanding zone of hard metal about the ogival is most depressed and strongly and extensively supported by the under layers.

The subject of caliber in the attack of face hardened plates is important. The question may be asked, Would a face hardened plate, barely capable of resisting a certain caliber of projectile, be unable to resist a larger caliber having no greater energy?

The area of zones in the ogivals of the projectiles exposed to like resistance in the two instances vary as the calibers, but the sections of the projectiles along the planes of greatest weakness vary as the squares of the calibers. The larger caliber would, for this reason alone, inflict more damage on the plate before being broken up. Also, as its energy consists in a much larger degree of indestructible, or at least less easily diverted mass, and less of velocity, it would produce an equal amount of damage upon the plate with a proportionately smaller loss of velocity than the smaller caliber. From this it is evident that of the two projectiles the lighter, with less resistance to crushing, has its velocity diminished much more suddenly and violently than the larger caliber with broader planes of resistance. It would therefore appear that when the target is superior to the gun, and as the vast majority of impacts in action will be oblique where this will be the case, the larger the caliber, even with the same energy, the greater the damage inflicted. The introduction of armor of increased resistance is certain therefore to bring about an increase in the calibers of the guns.

On the other hand, when plate and target are about evenly matched, the larger caliber must break away a greater volume of the plate before perforation, this volume varying as the squares of

the calibers. The resistance of the plate as a whole is also more certain to be felt against the slow moving projectile. Again, the larger ogival tends to concentrate its attack on each successive strata more than the smaller one; that is, it breaks away as much of the hard face as the latter with but a fraction of its penetration, so that if there should be a plane of weakness or inferior strata, there would be greater danger of breaking the plate up in detail. This is seen in the attack of laminated or piped plates by large calibers, when the back bulge is broken out in slabs.

ADDITIONAL NOTES AND CORRECTIONS.

With the ultimate object of correctness in the paper, Lieutenant Ackerman submitted the following additional notes, giving credit when due.* They were submitted after the discussion.

At the end of the first paragraph, page 8:—It has been suggested, for example, that the gas check disks referred to, having been cut from round bars were suffering from radial forging strains; had they been "upset" before being machined and tempered, or subjected to a long annealing, they would have tempered without difficulty.

At the bottom of page 20:—This paragraph is, as Mr. Howe states in the discussion, incomprehensible. It should read "The lime probably took up moisture from the air, becoming slaked, while the charcoal absorbed oxygen."

In regard to the foot note on page 21, CuO should be Cu_2O. See criticism by Mr. Howe.

After "constraint" in the middle of page 29:—This statement needs a generous qualification; chemical affinity is potential energy, it can exert stress only as a result of its satisfaction as indicated in the following paragraph. See discussion.

After the last complete paragraph on page 29:—This statement is incorrect; change of carbon from the "cement" to the "hardening" form is dependent only upon the temperature.

After "hardness," line 4, page 30:—This refers to hardening for *tempering*. See Howe, Metallurgy of Steel, page 22, §39.

* Three engravings used in the printing were kindly lent to the Institute by Mr. W. H. Jaques, having been used in his article in the *Engineering Magazine*.

After "elasticity", line 4, page 33:—This statement should be qualified so far as the words "*largely* increased" are concerned. It is found that the exterior film of a hardened cylinder is more dense than the interior. Also that the modulus varies nearly with the seven-thirds power of the density. See discussion.

After "plate," line 3, page 35:—That is, the plate would be affected to a greater depth.

"Ackerman," line 2 from bottom of page 35 should be "Akerman."

After "fluid," line 2, page 37:—This statement should be materially qualified. There is considerable expansion before the melting point is reached, although at that point the metal is more dense than at 1200° F.

After "This evolution", line 4, page 37:—This reference is believed to be incorrect; it is not essential, however, to the argument.

After last complete paragraph, page 37:—Professor Abel's experiments indicate that the condition of the carbon is hardly changed in wire drawing. This, however, is not essential, it is known that by forging through the critical point some carbon is retained in the "hardening" form; my contention is that pressure exerted at that time has the same effect. See Howe in discussion.

After line 22, page 39:—This apparent contradiction of views between Messrs. Brustlein and Howe is due to an error of my own. They are both correct. The former refers to the effect of varying percentages of carbon. The latter to the effect of *treatment* in steel containing any particular percentage of carbon.

On page 5, 11th line from the bottom:—"A 28 per cent. carbon plate" should read "A .28 per cent. carbon plate." Page 16, third line, "Roma shoals" should read "Romer shoals." Page 18, seven lines from bottom, "25 per cent." should read .25 per cent. Page 45, line 4 from top, "90° cone" should read "45° cone."

DISCUSSION.

Mr. WM. ALLEN SMITH.*—I expected to have sent you before this some remarks on the chronology and details of the negotiations between the late Mr. Harvey and the Naval Ordnance Bureau, but I have been laid up with an attack of grippe, and have been so pressed with other matters that I have not been able to get into shape the criticism of your paper which you asked for. I may, however, remark, that on page 5 it appears to us you give rather more credit to the Navy Department than is quite just, in view of the fact that Mr. Harvey had perfectly well defined views of what he wanted to accomplish before he saw Commodore Folger; and really by his presentation of his views so interested Commodore Folger as to induce the Commodore to recommend the experiments by the Navy Department which were subsequently made, and which showed the correctness of Mr. Harvey's views as to the best method of making a perfect armor plate.

We would also remark that we do not know and do not believe that what Mr. John D. Ellis did, in respect to applying the process of cementation to armor plate, amounted to anything more than a crude, abortive, and abandoned experiment; and in view of the fact that Mr. Ellis did nothing more than employ the ordinary cementation process, it is going rather too far to describe what he did as the "Ellis Process."

In the second paragraph on page 8, there is a slight error concerning the Schneider plate, which, as a matter of fact, was both super-carburized and hardened at the Washington Navy Yard, and was tested in February, 1891.

The erection at the Washington Navy Yard of the furnace for treating this Schneider plate was begun in November, 1890. These matters of dates are of course of minor importance. But it seems desirable to mention that Mr. Harvey, early in his negotiations with the Navy Department, and in support of his views, exhibited to Commodore Folger a block of steel, one side of which had been treated by his process, and had been made so hard that it could not be indented by a center punch driven by a sledge hammer. The exhibition of this small block of steel to Commodore Folger preceded the completion of the arrangement by which the original 6-inch plate was sent to Newark to be Harveyed.

I will only add that your contribution to the literature of face hardened armor is both valuable and timely.

Mr. H. M. HOWE, Boston, Mass.—We must thank the author for a great deal of very valuable information which he gives as to the actual procedure in Harveying and hardening armor, and for his interesting and suggestive propositions. As a metallurgist I must compliment him on the

*Discussion addressed to author.

amount of very recently published information with which he has familiarized himself on the exceedingly difficult and complex question of the hardening of steel. So difficult is this question, however, that there are some points on which I can perhaps set him right, and others as to which I should be glad to learn his authority: and so it is with the question of Harveying. Let me touch on these before taking up his main contention that gashing should increase resistance.

Cementation.—On page 21, line 6 and foot-note, the author, while correctly asserting that the phosphoric acid of bone-charcoal is not reduced in cementation, yet thinks that its phosphorus acts as a deoxidizing agent, as phosphorus does in reducing copper-oxide in making phosphor-bronze (by the way, it is cuprous oxide, Cu_2O, that the phosphorus in this case reduces, not cupric oxide, CuO, as the author says). This must be a slip of the pen. The unreduced phosphoric acid of the bone-charcoal, a fully oxidized compound, of course cannot take up more oxygen, and hence cannot deoxidize any other substance. In making phosphor bronze we use, not phosphoric acid, but phosphorus in an unoxidized and hence an oxygen-taking form.

On the same page, line 17, what is his authority for the assertion that cold iron buried in charcoal absorbs carbon even without the aid of heat? This must be an error.

Why quote, on page 20, line 26, "Dannemora iron" (by the way, one of the brands of iron especially noted for its freedom from phosphorus), "gives out an odor of P when twisted at a red heat?" Such an assertion is incomprehensible.

The same page, the last three lines. "The highly oxidized lime" (I had supposed that lime was a perfectly definite oxide of calcium, and that all lime was equally oxidized), probably took up moisture by selection of H from the air" (but whence is to come the oxygen which, uniting with that hydrogen, could form that moisture? surely this cannot be serious) "as well as C from the carbon present in the charcoal." What kind of compound was then formed between lime, water and carbon? A hydrated oxycarbide of calcium? To form lime-carbonate we need oxygen, not hydrogen.

Page 21, line 31. "On heating, the carbon is expelled from the limestone and unites with the oxygen . . . above." Can it be necessary to explain that, when limestone is heated, not carbon but carbonic acid is liberated?

Page 22, lines 4 to 14. "Soda ash frees the metal (iron) of oxygen." That soda ash, carbonate of soda, an already fully oxidized substance, is further to take up from solid iron with which it is in contact the oxygen which that iron does not contain, does not call for much comment. "The calcined lime eliminates the oxygen . . . in the retort." Here again, a fully oxidized stable substance, lime, is to take up oxygen. "Pure cyanogen-

gas is generated, which permeates the metal, carrying with it the free tungstic acid which tends to give the metal greater hardness." Without further explanation or evidence, we must regard this as unworthy of serious attention. Tungstic acid (anhydride) is not volatile. When heated as here with charcoal, it is reduced to metallic tungsten and tungsten dioxide. Tungsten volatilizes at about 3400° F. (1900° C.). But if tungstic acid were carried into the metal as here asserted, what good would it do? It is not tungstic acid, but metallic tungsten that hardens steel.

On page 23, the last four lines, the author says that it seems that in Harveying iron and carbon both volatilize, "when of course the formation of a definite carbide would naturally follow." Carbon has the power of migrating through hot plastic iron, and in Dr. Fleitmann's experiments, to which the author refers, it was reported that iron had the power of migrating in hot plastic nickel. Later experiments have shown that lithium can migrate in hot plastic sodium-silicate glass. These migrations in plastic substances are extremely interesting and instructive: they remind us of crystallization in like masses; but they do not imply, they hardly suggest volatilization. It is in the highest degree improbable that either iron or carbon volatilizes as such in case-hardening or Harveying. Nor, if they did volatilize, would it at all follow as the author asserts that "the formation of a definite carbide would naturally result."

On page 26, line 3, the author asserts that iron contracts in heating from 1832° F. (1000° C.) to the melting-point; on page 37, line 1, that it contracts in heating from 1200° F. (649° C.) to the melting-point; and in line 4, that the recalescence is accompanied by contraction. In each respect he is completely and curiously mistaken. Indeed, the contraction of iron in cooling from bright redness down to the recalescence-point, and its expansion at that point, are notorious, and if I remember aright, are what led to the discovery by Gore of the recalescence.* The enormous shrinkage which occurs in the early part of the cooling of steel castings, and which is one of the chief stumbling blocks in their manufacture, the like contraction of steel ingots, of rails, plates and other products in cooling are so well known and such obvious contradictions of the author's assertions, that one fancies that this must be a case of heterophasia, of saying the very opposite of what is intended. See page 109, J. I. S., 1891.

On page 37, four lines from the bottom, he seems to quote, as an explanation of the increase of strength of steel caused by wire-drawing, that the pressure which accompanies it forces the carbon into combination, by which he must mean, forces it into the hardening state, because most, and usually all, of the carbon in steel is in any case combined. Now, as wire-drawing causes like strengthening effects not only in the softest iron and steel, the freest possible from carbon, but also in all other malleable metals

* Outlines of the history of this matter, together with many references, are given on pages 187 and 188 of my "Metallurgy of Steel."

and alloys so far as we know, it would not be reasonable to suppose that the like effect in case of steel is chiefly due to so unlike a cause as forcing into combination the carbon which these other substances lack. But, quite apart from the extreme unreasonableness of such a supposition, we have Abel's experiments showing that these cold-working operations do not transfer the carbon to the hardening state.*

While the reactions on pages 24 and 25 by which the author explains the chemistry of cementation may be true, yet I believe that the operation is far more clearly explained by two well-known, simple, fundamental reactions,

$$2CO = C + CO_2,$$

by which carbon is deposited within the metal, where its absorption needs no explanation, and

$$CO_2 + C = 2CO,$$

by which the resulting carbonic acid renews the supply of carbonic oxide, and thus enables a small quantity of oxygen initially present to transport an indefinite quantity of carbon into the iron. This transportation of the carbon from the charcoal into the iron is all that needs explaining. There may be other intermediate and side reactions, but these which I have just given seem to be the end-reactions which suffice to explain the whole clearly. Oxidation of iron may occur as Lieutenant Ackerman supposes, but if so, it appears to be only an intermediate reaction, which serves rather to confuse than to clarify matters. For example, his deduction that there is an exhaustion of oxygen which must stop the operation seems to spring from this, and is probably misleading.

Hardening.—The third paragraph of page 29 argues that the smaller density of hardened than of unhardened steel in itself implies stress. Stress there no doubt is in hardened steel; but we infer it from other evidence. The mere lightness as such might be readily explained by difference in chemical constitution. In the following sentences he seems to think that unsatisfied chemical affinity may create stress; this seems to be a confusion of ideas, or a misuse of words.

Immediately below, and also in the last three lines of page 34, he naturally mistakes the results of Professor Langley's experiments. These showed that quenching steel, even from as low a temperature as 108° C. lightened it somewhat. They have been repeatedly quoted as proving hardening. But they merely showed that this quenching made the metal slightly lighter. No measure of hardness was attempted, nor have I ever seen any reason to believe that the metal was made in the least harder.

Near the end of page 29 he says that the hardening tendency is said to be proportional to the duration of the temperature of hardening. I have never heard this suggested before. So far as my observation goes, all the evidence tends to show that when steel is raised to a given tempera-

* Trans. Institution Mechanical Engineers, 1881, page 703.

ture, measurably above the critical point, W, the degree of hardening is practically independent of the length of time that the steel is held there. In other words, the change from cement to hardening carbon seems to take place with very great rapidity. No considerable length of time is needed to complete it.

On page 39, lines 10 and 11, the author falls into the curious error of supposing that manganese steel forges particularly well and "welds with great facility." Would that it did! Unusual precautions are required in forging it; even after these have been discovered and adopted, forging it is no easy matter, and as for welding it, why nobody thus far has succeeded in welding it properly so far as I know, even with great experience in electric welding.

From among the assertions which the author makes or quotes, some of which I fear must be wrong, I select the following, to ask him to give us his authority.

Page 27, line 7. "That steel of low tenacity carburizes with greater ease than other steel" (this is as I understand him).

Page 27, line 5. "It is said that the porosity of steel is generally in an inverse ratio to its tensile strength."

What is the porosity of steel, and how does one determine it? Speaking broadly, the density of steel is inversely as its tenacity. If we were to draw any inference from this as to porosity (and I for one should not dare to), it would be that the porosity, which should if anything be inversely as the density, should be directly as the tenacity, and not inversely as the author has it.

Page 33, lines 1 to 4. He asserts that water-quenching highly-carburized metal *greatly increases* the modulus of elasticity. Such evidence as I have met agrees with his previous and opposing assertion (page 32, line 26), that water-quenching has little effect on the modulus. The high tenacity, 400,000 pounds per square inch, which he quotes apparently as indicating an increase of the modulus, is no more evidence as to the modulus than the weight of a book is as to the weight of its author. The detailed information as to the modulus implied on this page should be of great value.

Page 30, line 3. "The more slowly the metal is heated to the higher temperature, the tougher it becomes without loss of hardness; this toughness increasing with the the length of time of exposure to that temperature." I can recall no evidence even pointing in this direction.

Page 34, seventh line from the bottom. An unqualified assertion that "Both the tensile strength and *ductility* of the mildest steels are greatly *increased* by quenching." My own extensive tests* had showed that quenching from above the critical point greatly *lessens the ductility* of all the steels which I tested, including one with 0.09 per cent. of carbon,

* "The Heat Treatment of Steel." Trans. Am. Inst. Mining Engineers, XXIII., p. 466, and especially p. 531.

which is certainly among "the mildest steels." There are some things which suggest that quenching from *below* the critical points, below which no true hardening occurs, may increase the ductility. This does not, however, help the author at all, who from the context evidently refers to quenching from above the critical point. He must have some full data of which I am ignorant, unless, as I fear, he is completely mistaken.

On page 35, line 1, as an inference from the assertion on which I have just commented, he further asserts: "It is evident, therefore, that the more sudden and complete the chill, the greater the increase of toughness in the body and back of the plate." As the context shows that toughness here means ductility, his conclusion seems to me not only far from evident, but in the very highest degree improbable.

To the same apparent error I ascribe his mistake on page 32, lines 19 to 25, that, save at the very surface, the plate is decrementally *toughened*, not decrementally *hardened*. Here he appears to be completely in error.

On page 8, line 6, he says that doubtless deleterious components are volatilized in the Harvey process from inferior metal. The volatilization of sulphur has been observed under like conditions; but has that of any other deleterious component?

On page 37, line 2, he quotes the specific gravity of molten steel as 8.05. This is surprisingly if not improbably high.

Let us now consider the author's main contention that gashing the face of a plate will

(1) Cause it to heat more quickly, and

(2) To carburize more quickly, thus saving time in Harveying;

(3) By increasing the pressure on the face of the plate will increase the degree of hardening for a given temperature, thus permitting the use of a lower quenching temperature, and finally, thus leading to less severe stresses within the plate; and

(4) Will increase the resistance to penetration. Let us consider these separately.

A plane parallel with the face of the plate, and slightly below its surface so as to lie just tangent to the bottoms or troughs of these gashes, divides the plate into two parts, a solid unbroken part, quite like the whole of any ungashed plate, and a lot of ridges or other elevations rising from this solid part, consisting of the steel left between the gashes. According to the direction of the gashes, these elevations may be true ridges or simply peaks; if the gashes are far apart, the ridges become table-lands. But, whatever their shape, let us for simplicity call this part of the plate above the bottom of the gashes the "ridge" part, and that below their bottom the "body" part.

1. *Heat Absorption.*—We may concede that the existence of a properly proportioned ridge part between the body part and the source of heat might hasten the heating of the body part, because the greater surface of

the ridges would absorb heat more quickly, and because the high conductivity of the metal would quickly transfer into the plate any heat taken up by the ridges.

But it seems to me that the saving of time and fuel, while it might exist, would be inconsiderable,—so slight as to be wholly unimportant.

2. While the increase of surface due to gashing would cause more carbon to be taken up per hour by the plate as a whole, yet this excess would, I believe, be found in the ridge part. The ridge part would retard the carburizing of the body part, because all the carbon which reaches the body must now pass through the ridge part, save what little enters at the bottoms of the troughs between the ridges. The case is wholly different from that of the mere introduction of heat. In the latter case, the fact that the ridge part separates the body part from the source of heat may well be outweighed by the high thermal conductivity of the metal, which would transfer into the plate with extreme rapidity the increased quantity of heat which its increased surface led it to absorb. Not so with the carburizing gases, however. The ridge part would, in effect, stand as an irregular barrier to the carburizing action, which would have to reach the body through the ridge part, and therefore much more slowly. We must remember that, while heat passes by conduction through iron quicker than through air or through the atmosphere which bathes the plate, yet the reverse is probably true of the carburizing action.

3. While there is much to suggest that pressure increases the degree of hardening caused by any given quenching, I see no reason to believe that it plays an important part. But, if it did, then it seems to me that the author's gashes should have exactly the opposite effect from what he supposes, and should lessen rather than increase the pressure.

When a plate is quenched, its skin presses on its interior because the skin cools faster, and hence contracts faster than the interior. This of course at first throws the skin into tension, the interior into compression. The pressure of the skin on the inside may be likened to the tightening of a strap. A gashed skin is like a crimped strap, with corrugations transverse to its length. Clearly, for given shortening an initially crimped strap will press less tightly than one initially straight. So, it seems to me, that, for given contraction, a gashed skin must press less strongly on the underlying parts than an initially straight, smooth skin.

Gashing might oppose flaking. The surfaces of least cohesion should, in a gashed plate, be roughly parallel with the gashed surface, because the variation both in carburizing and in hardening would run roughly parallel with it; and such irregular surfaces would be less likely than plane ones to coincide with the surfaces of high stress.

4. Whether because of, or in spite of my ignorance of resistance to penetration, the argument that it should be increased by gashing seems to me utterly fallacious.

First, let us recognize clearly that, besides increasing the hardness proper, Harveying and quenching also increase enormously the compressive strength and tenacity, and their resultant, transverse strength, all beneficial, and also brittleness, a most injurious property. Hardness proper and compressive strength, both composite quantities, with many elements in common, are yet distinct. Chilled cast iron and quartz, each at least as hard as hardened steel, have little compressive strength and little tenacity under impact. I believe that the author makes a capital mistake in confining his attention unduly to hardness proper, which I believe aids penetrative resistance but little, and neglecting the transverse, compressive, and tensile strength, which I believe are the main components of resistance. The brittleness which accompanies these beneficial effects of hardening, of course, as such, lessens resistance.

Let us resolve the resistance which a hard face offers to penetration into what I suppose must be two of its chief components, (1) normal resistance parallel with the axis of the projectile, and (2) *radial* resistance which the face offers to being driven parallel with itself, radially away from the point of impact, as the ogive progressively forces its way farther and farther into the plate, and stretches the holė out wider and wider.

The normal resistance is like the support of a snowshoe, or of thin ice on a pond; it arises from transverse strength. The gashes are equivalent to corrugating snow and snowshoe, or ice; in either of these cases we may admit that corrugation might increase the transverse strength, and that the normal resistance of a gashed, *i. e.*, corrugated half-inch thickness of face, reckoning from the crest of the ridges to half-inch below the troughs of the gashes, might be greater than that of a plane half-inch. This means that the normal resistance of a 10-inch plate with ½-inch gashes might be greater than that of a 9.5-inch ungashed plate; but I do not see clearly that it should be as great as that of a 10-inch ungashed plate.

But when we come to radial resistance the case is far worse. The isolation and the consequent exaggerated rate of cooling of the ridges would, indeed, give them increased compressive strength, but also increased brittleness. This isolation, the presence of these gashes between the ridges, must, however, deprive them of lateral support, and must thus affect most unfavorably both these effects of the exaggerated hardening. For on the one hand it makes their compressive strength useless for radial resistance, just as a weak foundation makes the strength of a strong column useless; while on the other hand it must, I fear, make their brittleness all the more damaging. Thus I fear that, as regards radial resistance, the ridges approach the condition of grains of sand or emery, hard but useless, attached to the body of the plate.

The hardening, and hence the tensile, compressive and transverse strength of the body part, are of course greatly lessened by the retarded cooling which the interposition of the ridge part between it and the water

causes. Thus the gashing in effect concentrates both the beneficial and the harmful effects of hardening, the strength and the brittleness, into the ridges, where the beneficial ones are inoperative and the harmful one is more noxious. This, it seems to me, is likely to outweigh enormously any supposed gain in normal resistance; and I fear that a 10-inch plate with half-inch gashes would be much weaker than a 9.5-inch ungashed plate, as well as far more costly. One may not prophecy in such complex questions; but these considerations seem to me to deprive the proposition of all promise.

Lieutenant W. IRVING CHAMBERS, U. S. N:—I have found Lieutenant Ackerman's valuable contribution to the literature of armor very interesting and instructive, and I can only hope to add to its interest by a few remarks concerning the process briefly alluded to in the second paragraph on page 41. This is known as the Chase-Gantt process and was discovered at the Midvale Steel Works, Philadelphia.

The fact that the best, if not all, of the modern armor-piercing projectiles are made of chrome steel is good evidence concerning the shock resisting properties of that metal and the capacity of that metal for being worked and treated under the hammer or in the oil bath and annealing furnace. Although chromium has given the best results in their armor plates, so far, the patents of these gentlemen cover the use of manganese, tungsten or any other element or alloy they may choose to employ in their special way. However, the metal of their entire plate is not strictly "chrome steel" and it is well to note that this is *chrome faced* steel only. The discovery of a comparatively cheap and simple method of introducing chromium and carbon together into the face of a plate *by absorption*, during the process of casting, marks a new and distinct era in the treatment of steel by alloys.

The bed of the mould is simply prepared with the desired alloy and baked to sufficient hardness and then the molten metal, nickel steel or steel of any desired grade, is quickly poured, as in a simple casting, leaving one or more heavy risers to feed the shrinkage as it slowly cools.

In this easy "method of cementation" the molten metal fuses the alloy, the chromium rapidly penetrates the lower face and, on account of its great affinity for carbon, carries the latter with it to a depth which is readily regulated by certain details in the process. It is supposed that the best results will obtain from a depth of hardness equal to about one-fifth the thickness of the plate. After casting, the plate is oil tempered and annealed as often as desirable and the face is then water hardened as with the Harveyed plates. The interior "pockets," which Lieutenant Ackerman shows to be so important, are always formed in this case by the hooks or projections of the hardened part which penetrate the softer part during the process of casting, or while the carbonized chromium alloy is penetrating the molten mass.

These desirable hooks thus formed are, of course, unevenly distributed.

They may, however, be readily accentuated, regulated, or produced in any desired form, square or otherwise, in the interior, by suitably preparing and placing the alloy in the mould with that end in view, and the face of the plate after casting will be perfectly smooth.

Such a plate, with a homogeneous soft back of mild steel evenly graded in toughness to a hardened surface that cannot be touched by a specially hard tool-steel center punch, seems to approach the theoretical condition mentioned on page 64. However, as Lieutenant Ackerman says, it is possible to have the back too weak to satisfy the desired conditions, but if the simple cast steel of the Chase-Gantt plate be found too weak, it can be forged or rolled down to any desired extent. For example, one of these plates, cast 11 inches thick with a hardened face about 2 inches deep, was heated and forged down to 6½ inches thickness; a piece of this was then heated and rolled down to one-half inch thickness, in which condition the hardened face was found to have been reduced almost proportionately, *i. e.*, the final thickness of the hard face was about one-eight of an inch.

The patentees of this process think that they will be able to produce results equivalent to the best service armor in plates simply cast, of the same thickness, without forging; *i. e.*, through the quality of the cast and the invisible kneading that occurs during the oil tempering and annealing processes. Of course we hope they may, but I am not so sanguine about such a marvelous achievement. It seems certain, however, that they are able to produce a greatly increased depth of hard carbonized surface in conjunction with a wonderfully tough and homogeneous back. There is, apparently, no difficulty in casting a plate thirty or more inches thick with a hardened face from three to six inches thick, and in forging or rolling this plate down to ten inches thick with a hardened face from one to two inches thick. It is also, apparently, easier to produce uniformity of results in thick plates than in thin ones.

In consideration of the valuable experience gained during the development of our present service armor and of the relative simplicity and cheapness of this rival, I anticipate a speedy development of chrome-faced armor and a considerable increase in its resisting power over that of the present service armor.

Lieutenant C. A. STONE, U. S. N:—I have read, with much interest, Lieutenant A. A. Ackerman's paper on face hardened armor, and I consider it a most valuable contribution, and one which brings together, in an able manner, the recent results on this subject with most interesting explanations. I would like to see Lieutenant Ackerman's proposed armor plate made and tried, and I hope this will soon be done. Lieutenant Ackerman's explanation of the resistance offered by the Harveyed plate by being elastically dished under the impact of the shell, is very interesting. The resistance which a plate would thus offer would appear to be similar to that offered by a circular disc when loaded at the center and supported

around its circumference ; a mathematical expression for this I have never seen.

On page 52 are given the results of the trial of 4″ shell against a 3″ Harvey plate with a velocity of 600 f. s ; no penetration was attained and the shell were smashed. The result was caused by the resistance of the plate to being dished elastically. From this it would appear that, for a certain velocity, that resistance is sufficient to demolish the shell. I remember seeing at the Washington Navy Yard, some years ago, a plate which had spiral springs behind it, which had been fired at. Several large holes through the plate indicated the result. I do not know who was the author of this experiment. In this case the springs would offer but little resistance, and the inertia of the plate would allow it to be penetrated before the springs could do much work, even were they stiffer. In the case of the thin Harvey armor plate, the resistance it offers under impact to being elastically dished is very great ; the plate, in the neighborhood of point of impact, being a most powerful spring. Thick Harvey plates will dish elastically less than the thin ones, of course, as the carbonized and tempered part is a less portion of their thickness and mass ; for this, among other reasons, thick Harvey plates will be relatively more easily penetrated than the thinner ones.

Lieutenant Ackerman has not said much about the effect of the long continued high temperature of carbonization on the body of the thick plates. This tends to undo, to a great extent, the good effect of the previous forging, tending to render the body of the plate crystalline. Experiments are being made for the purpose of determining the effect of additional forging after carbonization and before tempering. A 14″ plate in which this was tried is now awaiting ballistic test.

On pages 39 and 41 of Mr. Ackerman's paper mention is made of nickel chrome and of nickel manganese Harvey plates.

If the additional forging after carbonization should not prove sufficiently successful in the case of the thick nickel steel Harvey plates, it appears to be probable that better results may be attained by the addition of chromium or manganese.

On page 33 of Mr. Ackerman's paper, it is stated that at a certain point beneath the surface of a face hardened plate, etc., the original modulus may be found.

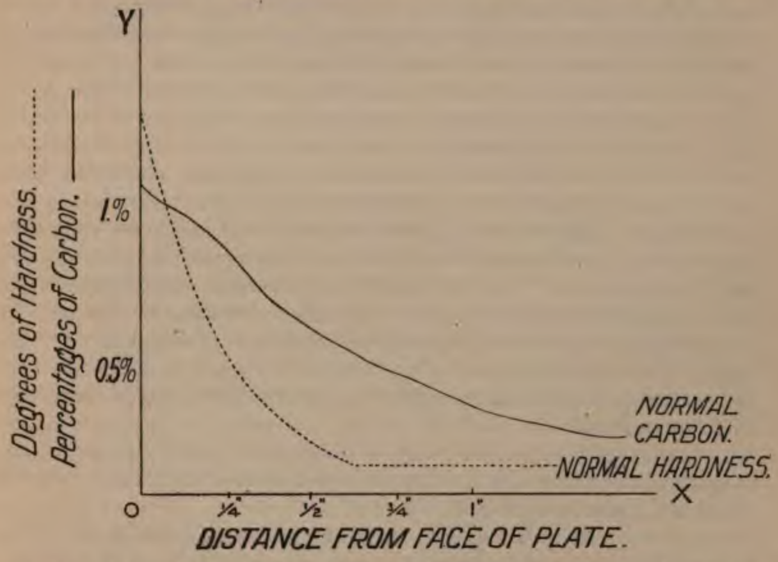
I think that experience shows that ordinarily the carbonization extends to a greater depth into the plate than is of any use with our present means of tempering. This leaves behind the tempered face a stratum of metal higher in carbon than is desired. With our present methods of carbonization, to obtain the required amount of carbon near the surface, this unnecessary and objectionable depth of carbonization appears to be unavoidable. Experiments upon this point are much needed, but the ballistic test is the only means of determining with any certainty what results heve been

obtained. This is, of course, expensive and also very often not decisive, the result being due to other causes than those the effect of which we seek to determine.

The percentage of carbon, at different depths from the face of a carbonized plate, is determined by chemical analysis at each one-sixteenth of an inch of depth, until the normal amount of carbon is reached; this is at a depth of an inch and a quarter or an inch and a half, usually. These percentages of carbon may, of course, be laid off as ordinates on any convenient scale, the abscissas being the distances from the face of the plate at which these percentages occur. A curve drawn through the ends of these ordinates will give, for any case, what we may call the curve of carbon for that plate.

With our present method of tempering, the chill only reaches a depth of about five-eights of an inch; all parts of the plate to this depth are more or less tempered; the amount of tempering at any point would evidently depend, the tempering means being the same, on the amount of tempering carbon at that point, and the effectiveness of the chill, which depends probably on some function of the depth.

If we had some recognized method of determining hardness, we could,



together with carbon determinations in a plate, make hardness determinations at the corresponding depths. These degrees of hardness could be laid off as ordinates on the same figure as that showing the curve of carbon, and if a curve were drawn through the ends of those new ordinates,

it could be called the curve of hardness. This latter curve would become parallel to the axis of abscissas at a point about five-eighths of an inch from the origin, the curve of carbons becoming parallel to this axis at a distance of an inch and a quarter or an inch and a half from the origin.

A comparison of these two curves would show the relation which exists between the amount of carbon and the degree of hardness obtained by the tempering, at the different depths, and, if this comparison were made for a number of plates, it is probable that information would be obtained therefrom which would be of much use in the manufacture of Harveyed armor plates. A sketch is enclosed to illustrate these curves, the full line being the curve of carbon, and the dotted line the imaginary curve of hardness.

Lieutenant ACKERMAN, U. S. N.:—I have much for which to thank the gentlemen who have discussed this paper. Few practical or business men care to correct or elucidate views which may benefit their possible competitors; others will not venture into the realm of conjecture where the disclosures of a few months to come may confute the expressed opinions of to-day.

I appreciate all the more then the honor which Mr. Howe with his great wealth of experience has done me in criticizing the paper at such length. He has pointed out errors in it which shall be frankly admitted and called attention to statements which require substantiation. He has also made certain other strictures in which I can follow him neither in logic nor in fact. However, I am assured of this, the careful reader will be able to find no error or doubtful statement in this essay which is any more necessary to the line of argument in favor of the proposed new armor plate, than a fungus is essential to the existence of the tree in which it lives.

Mr. Howe's disgust at the peculiar assortment of patent claims for various processes of cementation would be amusing were it not for the fact that he appears to hold me responsible for the errors which they contain. These claims were quoted as an interesting exhibition of the peculiar views held of the process of cementation by certain practical minds. It is expressly stated at the foot of page 22 with regard to them, that few explanations are satisfactory, while many claims are based on unsustainable assumptions.

Erroneous as they are, however, in theory, they will doubtless convey suggestions to some who it is to be hoped will discern the soul of good that lies mingled in their evil.

Exception must also be taken to the frequency with which Mr. Howe declares express quotations which occur in the essay to be assertions, thus apparently attempting to force me to defend a position where I would be at a disadvantage, and in which in every instance noted I have no real interest at stake, especially when the matter is correctly stated at length elsewhere in the essay. I refer, for example, to his criticism of the quota-

tion on page 37 of W. Hempel's explanation of the increased strength obtained in wire drawing and cold hammering; also the remarks ascribed to Professor Barrett on the same page, that recalescence is accompanied by a contraction; also the first sentence on page 37, that metal becomes more and more dense when heated above 1200° F., until fluid. No assertion was made in these cases, in fact the words "it is said"—were used as disavowing any assumption of responsibility. The behavior of the metal at the critical points is fully explained on page 25.

Should his valuable work on the Metallurgy of Steel be read in this spirit, it would lead to endless contradictions.

For instance, on page 18 of that work this statement appears with regard to the effects of hardening, "It is said to raise the modulus of elasticity." This view of the effect of hardening on the modulus he contests in his criticism of my paper, if it was an assertion in his book, he is now in contradiction; if it was not an assertion, then many of his criticisms of this article cannot have been seriously intended.

The metallurgical premises of the essay which are criticized in the discussion may be grouped under the following heads:

1. That at the extremely high temperature employed in the Harvey process, *i. e.*, above that of molten cast iron, the gases of cementation are not only extremely attenuated, but the capacity of the metal for them is less than at a somewhat lower temperature when the metal is less dense. [No denial is made of the statement that at this high temperature much of the carbon introduced is graphitic or uncombined, unable to assist in increasing the hardness in the subsequent quenching, and to the presence of which in fact the softness and weakness of the metal after cementation is in a great measure due. This intrusion of graphite occurs to a certain but far less extent even at the ordinary temperature of cementation, for it is well known that an analysis of cement steel taken after forging will give a greater percentage of combined carbon than if taken immediately after cementation. Lieutenant Stone has called attention to this fact in his remarks. It may be added that the Carnegie Steel Company had experienced some difficulty in obtaining the requisite hardness on the face of some very thick plates cemented at a high temperature; analyses showed a fair amount of carburization, but in addition, considerable graphite, which undoubtedly weakened the surface. One of these plates was forged slightly thinner, when the analysis exhibited a quite marked *increase* of combined carbon. Upon ballistic test, the plate showed far greater resistance than any other plate of equal thickness that has yet been tested.]

Under this head also come the objections made to the "volatilization" of iron at the ordinary temperature of cementation; the connection of cementation with porosity and porosity with tensile strength; and the increase of the density of steel when heated to a temperature approximating to the melting-point. Every one of these objections might be admitted,

however, and it would still remain apparent that the plate would be in a better condition both as regards crystallization and carburization if not heated above 2000° F. in cementation. In addition it is found that the edges and corners of plates are occasionally burnt, while unavoidable fluctuations of temperature sometimes cause hollows to be melted and scored into the highly carburized surface, which also shows large crystals.

2. Under the second head come the criticisms of the theory that pressure assists in retaining the carbon in the hardening form in quenching, and that therefore an arrangement of the surface by means of which the initial chill will immediately place an external layer of the metal of considerable thickness in a state of tension, and hence compression, thereby not only hastening and increasing its own tendency to harden, but bringing a more direct and powerful influence on the body of the plate.

Although Mr. Howe contends this theory in detail, it is quite satisfactory to note his final position. "While there is much to suggest that pressure increases the degree of hardening caused by any given quenching, I see no reason to believe that it plays an important part." Still it is well known that by forging through the critical point some carbon is retained in the hardening form. My object throughout has been to make use of every possible means of assisting the hardening ; nothing should be considered trivial when it works in the right direction.

Mr. Howe's experience and distinguished reputation should, however, command the most careful attention to every objection he has made. For that reason I will go more at length into the various details than would otherwise be necessary. There is this great advantage in *expert* criticism, it is certain to help a good thing.

CEMENTATION.

With regard to page 20, last three lines. This paragraph as it stands is indeed incomprehensible. It should read "Powdered charcoal takes up O from the air, while the quick-lime absorbs moisture and slakes."

Page 21, line six and foot note. Mr. Howe makes the following statement : "The author, while correctly asserting that the phosphoric acid of bone-charcoal is not reduced in cementation, yet thinks that its phosphorus acts as a deoxidizing agent." A contradiction is here implied though none exists. In the text it is said, "the basic phosphate is not reduced ;" in the foot note it is said: "It is the writer's opinion that P acts as a reducer of CO," there is no reference in the foot note to the basic phosphate of the bone-charcoal.

The use of CuO for Cu_2O is due to an omission unimportant so far as the idea conveyed is concerned ; it is not a slip of the pen.

Page 8, line 6. A strong doubt has been expressed by certain metallurgists, who combine sound theoretical knowledge with much practical experience, as to whether the Harvey and similar processes actually im-

prove inferior metal more than would be accomplished by careful annealing. The improvement in the gas check discs for example, is laid to the fact that the round bar from which they were cut contained *radial* forging strains which were released in the long annealing. Had the discs been *upset* before being machined and tempered, no trouble would have been encountered. It is asked, "Has the volatilization of any other component than that of sulphur been noted in the Harvey process?" In fact, no. Mr. Harvey's claim however is to carry on the treatment between the temperature of molten cast iron and that of about 3000° F. For some distance below the superior limit, various *reductions* will take place in the presence of the carbon gases. Chief among these is that of the oxide of iron found in overheated or burnt metal, rendering it brittle and of little value. It is well known that metal of this character can be made forgeable and capable of taking a temper when heated in contact with carbon. At the higher temperatures demanded in this process, the basic phosphate previously alluded to would also be reduced, and, as Mr. Harvey stated, would render the operation more rapid and effective, doubtless through assisting in reducing the oxide in the iron.

Page 21, line 17. With regard to cold iron absorbing carbon: In Landrin's Treatise on Steel, the following occurs: "Iron and carbon have a great tendency to unite even when cold. Iron left for some time in a mass of charcoal dust will become hardened, and by and by, may be transformed into steely iron." This work was translated by M. Fesquet, in 1868, so that it cannot be regarded as an authority on modern steel making; however, it would be absurd to suppose that M. Landrin, who was a practical man, did not know the difference between *iron* and *steely iron*.

Referring to the bottom of page 23, Mr. Howe says: "In Dr. Fleitmann's experiments, to which the author refers, it was reported that iron had the power of migrating in hot plastic nickel . . . It is in the highest degree improbable that either iron or carbon volatilizes as such in case-hardening or Harveying."

Dr. Fleitmann published the results of his experiments with various observations in *Stahl und Eisen*, vol. IX., pp. 9–12. I have been unable to gain access to the original memoir, but the following is from the Physical Property notes in the Journal of the Iron and Steel Institute, vol. I., 1889, p. 368:

"Some remarkable and regularly recurring phenomena . . . led the author to conclude that iron is volatile at a *medium red heat*, and experiments proved this to be the case . . . Further experiments showed that, although the iron is very volatile at this temperature, the nickel does not volatilize at all."

The dissimilarity of the words *Verflüchtigung*, volatilization, and *Wanderung*, migration, is so great that I am unwilling to accuse the staff of the Iron and Steel Institute of an error in translation.

fish destroyed by them. To estimate twenty per day as the number destroyed, if not devoured, by each blue-fish, is by no means extravagant."

Accepting the estimate by Prof. Baird of twenty fish eaten or destroyed per day by each of the 100,000,000 blue-fish, and allowing a quarter of a pound average weight for each fish, the destruction would exceed 29,000,000 tons for the 130 days they usually remain on the coast. The destruction of fish life from this cause alone is almost beyond comprehension, and leads irresistibly to the conclusion that Prof. Baird was right when in his report he stated that: "I am inclined to assign to the blue-fish the very first position among the injurious influences that have affected the supply of fishes on the coast."

Commissioner Baird planned from the first to avail himself of the services of volunteers in collecting statistics and general information, and, in accordance with this scheme, thousands of circulars were issued requesting the following information relative to the food fishes of the United States: Name of fish in question in different localities, geographical distribution, size, migrations and movements, relationships, travel, reproduction, diseases, parasites, artificial fish-culture, protection by law, capture, economical value and uses, remarks relative to foreign or domestic allies.

There were eighty-eight questions under these heads, and the replies contained a mass of statements and opinions somewhat inchoate, but nevertheless furnishing a fund of useful information not to be obtained, in the same space of time, by any other method.

A systematic examination of the fishery industries of the great lakes was among the first important investigations instituted by the Commissioner, and the flattering success of operations in that region affords conclusive evidence of the benefits resulting from the scientific explorations and practical work of the Fish Commission.

The co-operation of the Navy Department commenced in a modest way by the loan of a steam launch which was used at the Woods Holl station, during the season of 1871, for dredging and trawling. It was serviceable to the Commissioner also in making his personal inspection of the fisheries of Buzzards bay and Vineyard sound.

In this small way began a naval co-operation in the work of the Commission which has continued without interruption, to the

mutual advantage of both these branches of the general government. It steadily increased with the growth of the Commission, keeping pace with its comprehensive scheme of exploration, until finally their relations became much more intimate than is usual between independent departments of the government.

I have aimed to give a general idea of the origin, purposes, and methods of the Fish Commission without entering into detail or even mentioning all of the various branches of biological and physical research included in its scheme of operations. The rapid extension of its work in directions not contemplated at the time it was established not only required an increase in the personnel but involved an unusual amount of experimental work often resulting in the modification of methods to meet changing conditions. Yet the broad principles upon which its wide field of investigations is based remain practically the same.

The friends and advocates of fish-culture view with no little satisfaction the attainment of scientific and practical results far exceeding the anticipations of the most sanguine supporters of the modern application of this ancient industry.

The most notable legislative event in the life of the Commission was the enactment of a law by Congress, at the instance of the American Fish Cultural Association, approved June 10, 1872, providing "for the introduction of shad into the waters of the Pacific States, the Gulf States, and the Mississippi valley, and of salmon, white-fish, and other food-fishes, into the waters of the United States to which they are best adapted." The bill carried an appropriation of $15,000, and required that the work should be done under the direction of the U. S. Fish Commissioner. The artificial propagation and distribution of shad commenced July 2, 1872, and the following year 35,000 shad fry were successfully transported by rail from the Atlantic to the Pacific, and, in the presence of a few prominent citizens, deposited in the Sacramento river at Tehama, California. This attracted no attention except from the few who were directly interested, the people of the coast generally having little faith in the enterprise. Yet, from that apparently small and insignificant beginning the streams of California, Oregon, Washington, and British Columbia are to-day so plentifully stocked with shad that it is quoted lower in the markets of the west coast than in its old home on the Atlantic.

1. Is it a food fish?

2. What price will it bring in the market?

3. Can it be taken in paying quantities?

4. What is the best method of capture?

The Commissioner required the following additional information:

1. What is the character of its food, and is it sufficiently plentiful to afford a continuous supply?

2. What is the character of the sea bottom where the fish is found?

3. What is the temperature of the water at the surface and bottom, the specific gravity, and strength and direction of current?

The ichthyologists of the Commission christened the new species "tilefish" (*Lopholatilus chamæleonticeps*) and upon investigation it was found to be an excellent food fish, its market value approximating to that of cod; it could be taken in paying quantities with hand lines or trawl, and it found an unlimited food supply in the munida and other crustacea with which the region swarmed. The subsequent history of the tilefish is quite as remarkable and mysterious as its first appearance. It had come to stay, apparently, and, its value having been established, preparations were in progress to introduce it into the markets, when, in March, 1882, vessels reaching Atlantic ports from the eastward reported sailing through great numbers of dead and dying fish floating on the surface of the sea, which upon investigation proved to be, with few exceptions, the tilefish.

An officer of the Commission collated the reports from arriving vessels and found the area of floating fish to have been between 5000 and 7000 square miles, the aggregate loss in weight, after reducing the estimates of ship masters to one four-hundredth, reaching the astounding total of 719,360,000 lbs. Nothing more was seen or heard of the species until its appearance in 1893, after an absence of eleven years.

The necessity for a larger vessel for the purposes of deep-sea exploration finally became so imperative that Congress provided for its construction by an act approved March 3, 1881, "for the construction of a steamer for the prosecution of the work and investigations of the Commission of Fish and Fisheries, $103,000." Plans were prepared and bids received for her construction, but

U. S. FISH COMMISSION STEAMER FISH HAWK.

SHAD HATCHING ON THE MAIN DECK.

adopt any device that gave reasonable promise of increasing the safety, economy or efficiency of the vessel.

The Albatross was actively employed on the Atlantic until 1887, her field of operations extending from the Grand Banks of Newfoundland to Nova Scotia, to the bay of Fundy, and the coast of the United States from Maine to the delta of the Mississippi. In the West Indies it embraced nearly the whole of the Caribbean sea, the coasts of Yucatan, Cuba, and the Bahama seas.

Besides her regular biological and physical investigations, she steamed many thousands of miles to discover from whence came the great schools of mackerel, menhaden, bluefish, shad, and other species which annually visit our coast. Search for the lost tilefish was prosecuted from Martha's Vineyard to Cape Hatteras, and the Fish Hawk's lines of deep-sea exploration were extended seaward, midway between the outlying islands of Massachusetts and the Bermudas, when, for the first time in the history of deep-sea exploration, the beam trawl was successfully operated in the great depth of 2949 fathoms.

The schooner Grampus was launched in 1886, and has since been actively employed in her special work. There were various reasons for her construction, the greatest perhaps being the necessity for improvements in the general design and rig of fishing vessels. Speed is a vital element in the ocean fishing vessels of New England, and to economically secure it the tendency has been to build shallow and sharp vessels of great beam which gave them the requisite speed and answered the demands in moderate weather. The center of gravity was, however, carried too high for safety in heavy seas; and in ten years, from 1874 to 1883, inclusive, Gloucester lost eighty-two schooners foundered at sea, with a sacrifice of 895 human lives. The Grampus embodied the best features of our successful schooner yachts and pilot boats, and proved an important object lesson, having effected almost an entire revolution in the form and rig of Gloucester fishing vessels. Her duties have been largely on the fishing banks, among fishermen, introducing improved methods, and studying the present condition of the industry with a view of meeting future wants. She has done some biological work, and made an extended physical examination of the waters of the north Atlantic.

The death of Prof. Baird in 1887 caused many changes in the

organization and personnel of the Commission and its relations with other departments of the government. He exercised personal supervision over all branches of the Fish Commission for sixteen years, without pay, giving to this, his labor of love, much valuable time which nature demanded for rest. The rapidly expanding operations of the Commission embraced nearly every State in the Union; sixteen propagation stations had been established in various localities, producing annually hundreds of millions of young fry which were distributed from Maine to Texas, and the Pacific coast, by three cars specially constructed for the purpose, and several valuable species of foreign fishes had been acclimated and distributed in large numbers. Surveys of the oyster grounds on the Atlantic coast were in progress, and preliminary researches were being made preparatory to the artificial propagation of oysters and lobsters. The great station at Woods Holl had been completed, and the biological and physical researches conducted in its spacious laboratory and on board of the vessels of the Commission were approaching their greatest development.

At the time of his death Prof. Baird was Secretary of the Smithsonian Institution, in charge of the National Museum, and U. S. Commissioner of Fish and Fisheries; the conduct of any of these great institutions, with its attendant responsibilities, being sufficient tax on the energies and strength of one man. Yet they were under his personal administration for years, until finally his magnificent physique and matchless endurance failed, and the end came in the prime of life. The blow fell with all the more severity upon the Commission from his having retained personal direction over all its various branches; and Dr. G. Brown Goode, who, at the request of the President, assumed the Commissionership *ad interim*, found it necessary to give his immediate attention to the classification of the work and personnel, resulting in the promulgation of regulations, which, with a few unimportant changes, still remain in force. The present scope of the work of the Commission covers (1) the propagation of useful food fishes, including lobsters, oysters and other shellfish, and their distribution to suitable waters; (2) the inquiry into the causes of the decrease of food fishes in the lakes, rivers, and coast waters of the United States, the study of the waters of the interior in the interest of fish culture, and the investigation of the fishing grounds of the

Atlantic, Gulf, and Pacific coasts, with the view of determining their food resources and the development of the commercial fisheries; (3) the collection and compilation of the statistics of the fisheries and the study of their methods and relations.

Marshall McDonald, the present Commissioner, was appointed by the President in February, 1888. He had been in charge of fish culture and distribution under Prof. Baird, and being familiar with his methods, and the subsequent reorganization effected by Dr. Goode, he assumed his new duties under favorable auspices, and, through his able management, the Commission has steadily enlarged its field of action and general usefulness.

The completion of the Albatross and the results of her first season's exploration of the fishing banks were regarded with much interest by representative men of the Pacific coast, who from that time brought an ever-increasing pressure upon the Commissioner to send a vessel to the west coast to develop their sea fishing grounds, particularly those of Alaska, of which very little was known.

The construction of another vessel for the purpose was suggested, but it was finally decided to send the Albatross after she had made a preliminary examination of eastern waters; and, on the 4th of August, 1886, an appropriation was made by Congress for general repairs and for expenses of the voyage to San Francisco. She sailed from Norfolk, Va., November 20, 1887, with instructions to carry on *en route* such investigations as seemed advisable, considering the limitations of time and appropriation, the 15th of May, 1888, being fixed upon for her arrival in San Francisco.

Few vessels ever left port in better condition or more perfectly equipped; she had a full complement of officers and men, and a large corps of experienced naturalists. The voyage was interesting and instructive, furnishing material for an entertaining volume, but space will not admit of more than passing mention of ports of call and a few leading incidents.

Her first stop was at Santa Lucia, thence to Bahia, Montevideo, Straits of Magellan, and Sandy Point. Nearly a month was given to explorations in the straits and western Patagonian channels; thence to Lota, Panama, the Galapagos, Acapulco, La Paz, and San Francisco, arriving May 11, 1888.

The scientific results of the trip were very satisfactory in spite of the limits imposed; deep-sea investigations and shore collecting were vigorously prosecuted whenever practicable; 42 anchorages were made, the naturalists landing and making collections at 40; 90 dredging stations were occupied in various depths, and 127 soundings were made, some of them exceeding 2000 fathoms in depth. The study of the fishes of different latitudes added much to our knowledge of the distribution of species, and several were found entirely new to science.

The subsequent career of the Albatross in the Pacific, extending over a period of seven years, has been signalized by continuous activity and usefulness. Her summers have been spent in Bering sea and other Alaskan waters; and of the immense area examined by her in that region, 30,000 square miles may be designated as fishing banks on which cod may be found in paying quantities at the proper season of the year.

She explored the fishing grounds south of the peninsula of Alaska during the summer of 1888, extending her operations to the southern California coast later in the season, and finally to the Gulf of California, where a portion of the winter was spent in the investigation of the pearl and other fishing industries.

By direction of the President she conveyed the Senate Committee on Indian Affairs from Puget sound to southeastern Alaska in July, 1889, the remaining summer months being employed in the examination of the coasts of Washington and Oregon. March and April, 1890, were spent in exploring the California coasts, and the remainder of the season in surveying the fishing grounds of Bristol bay and other parts of Bering sea.

An important scientific expedition, authorized by the President and under the direction of Prof. Agassiz, was sent out the following winter for the purpose of investigating the biological and physical features of an extensive area including the west coast of Mexico, Gulf of Panama, Central and South American coasts to the latitude of the Galapagos, including that interesting group, also the Gulf of California. Returning to San Francisco in May, 1891, the President again diverted her from her usual occupation to carry U. S. Commissioners to the Seal islands in Bering sea, no other vessel being available at the time. The late fall and winter were devoted to the survey of a submarine cable route between the Cali-

fornia coast and Honolulu. Two lines were developed and preparations made to run a third when in March, 1892, she returned to the north on seal investigation for the State and Treasury Departments, the field of operations extending from the Straits of Fuca to Prince William sound, the Aleutian chain, and the Commander islands, off the Kamchatka coast.

During the seasons of 1893-94 she was attached to the Bering sea fleet, and performed patrol duty in addition to her special work. The Fish Commission was directed by act of Congress approved March 3, 1893, to make an annual inspection of the seal herd on the Pribyloff islands, and this duty has been performed by details from the scientific corps of the Albatross. Various and important duties which were not contemplated when she was built have thus devolved upon her from time to time, interrupting her regular work. Her cruising grounds extended over the broad area embraced within 60° north and 54° south latitude, and from 34° west to 166° east longitude. She has occupied 1566 dredging stations, made 5043 deep-sea soundings, besides thousands of physical observations not mentioned, and has steamed 164,118 miles.

A brief mention of her more important services to the Navy Department may not be devoid of interest as an illustration of the soundness of the Secretary's estimate of the value of "first mortgage" on a vessel of her class under naval organization.

Her first service under the Navy Department was from January to May 1884, sounding in the Caribbean sea and off the west coast of Cuba, and the examination of the bar at the mouth of the Magdalena river. During the last week of August, 1884, she acted as flagship for the Secretary of the Navy during the autumn manœuvres of the North Atlantic Squadron, taking the place of the Tallapoosa, which had been sunk by collision. From February to May, 1886, while on a cruise to the Bahamas, much deep-sea sounding and other hydrographic work was done for the Navy Department, and later in the same year a line of soundings was run in the North Atlantic at the request of the hydrographer.

Early in 1887 a series of experiments were made at the request of the Bureau of Navigation, relative to the ignition of gunpowder and coal gas by the fracture of an incandescent electric lamp, also a magnetic survey to determine the effect a dynamo in operation has on the compasses of a vessel.

U. S. FISH COMMISSION STEAMER ALBATROSS AT PORT OTWAY, WESTERN PATAGONIA, JANUARY, 1888.

[THE ALBATROSS IS NOW PAINTED WHITE.]

From October, 1891, to February, 1892, she made a cable survey between Monterey bay, California, and Honolulu, sounding two routes, one on a great circle, the other a rhumb line.

From March to August, 1892, although on a special mission under the State and Treasury Departments, she was subject to the orders of the senior officer commanding the Bering sea fleet, and used by him as occasion required.

From May to October, 1893, and again from April to October, 1894, she was attached to the Bering sea fleet under direction of the Navy Department, and did patrol duty in addition to her special work. In the performance of this service the vessel has been transferred temporarily to the Navy Department no less than four times, and retransferred to the Commission, without delay, friction, or changes of any kind occurring in personnel or organization.

It may be mentioned as a further beneficial result of the intimate relations existing between the Commission and the Navy Department, that the latter has been furnished from time to time with valuable hydrographic information, plans of anchorages, charts, and deep-sea soundings from remote and little-known regions, which have been of great service to the Hydrographic Office in the preparation of aids to navigation.

The success attending the general operations of the Commission steadily enlarged its sphere of action and entailed new duties and responsibilities from year to year. The artificial propagation of useful food-fishes is still by far the most important and extensive branch, and there has been a notable increase in the number of species under artificial culture. Among the great triumphs in this direction, if not the most important of all, is the successful and economical propagation of the lobster, which, it is hoped, may largely compensate for the wasteful methods and over-fishing which have been slowly but surely tending towards the extinction of this valuable crustacean.

Additional hatching and distributing stations have been operated on coast and inland waters, and the steamers Albatross and Fish Hawk and the schooner Grampus are actively employed each in its special work.

The gathering and systematic compilation of fishery statistics is an important branch of Commission work. Its officers collected fishery data for the tenth census, and continue to gather complete

annual statistics of the fishery industries of the United States, including whaling and sealing.

Without attempting a review of the various operations of the Commission in detail, the following brief synopsis will serve to illustrate its general growth, its present condition, and the practical results attending its operations during the fiscal year ending June 30, 1894.

Fish culture and distribution: hatching stations in operation	21
Number of States in which they are located,	13
Number of species hatched and distributed,	36
Fertilized eggs distributed	19,666,000
Young fry distributed, including 69,066,000 young lobsters	494,253,000
Adult fish distributed	1,921,000
States and Territories in which eggs or fry were deposited	All
Total number of deposits made	3,641

Number of distributing cars, 4; mileage of cars in distributing fish, 105,529; number of railroads furnishing free transportation, 49; number of miles of free transportation furnished by these roads, 65,093.

Floating property: steamers, 2; schooners, 1; steam launches, 9; boats, exclusive of those belonging to vessels, 53.

Naval contingent: officers attached to the Albatross, 9; officers attached to the Fish Hawk, 5; crew of the Albatross, 53; crew of the Fish Hawk, 37.

Commission employees, 170.

Total appropriation for 1894, $352,302.

The notable results of operations during that year, as shown by the preceding summary, are due to the systematic investigations and business-like methods by which the U. S. Fish Commission achieved its marked success and fairly earned its enviable position among the scientific and economic branches of the government.

U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.

THE HOWELL TORPEDO.

AN ELEMENTARY DESCRIPTION.

By LIEUTENANT ALBERT GLEAVES, U. S. Navy.

I.

The Howell torpedo is, in dimensions and general appearance, very similar to the Whitehead. Like the Whitehead it carries a war-head containing the explosive charge of gun-cotton, which is rendered operative automatically, during the run, and is exploded by contact with the target.

The Howell shows no trace of itself during its run, but at the end of its course when its buoyancy brings it to the surface, it is readily sighted by the smoke from the calcium-phosphide, a charge of which is placed, for practice runs, in a pocket on top of the torpedo.

The motive power of the Howell is the energy stored up in a fly-wheel, which is spun up to 10,000 revolutions per minute by a steam motor. This wheel weighs about 128 lbs.

The torpedo is distinguished for its great directive power derived from the gyroscopic properties of the fly-wheel.

The shell of the torpedo is made of a hard rolled metal composed of 80 parts of copper, 20 parts zinc, and a trace of lead. The model of 1894 is about 11 feet long and 14.2 inches in diameter. The shell is $\frac{1}{16}$ in. thick. The total weight of the torpedo, including the gun-cotton charge of 100 lbs., is something over 518 lbs. The positive buoyancy of the torpedo is 10 lbs.

The torpedo is divided into three sections, (1) the head; (2) the cylinder; (3) the after section. These sections are joined together by water-tight joints.

1.—THE HEAD.

Practice.—Contains water instead of gun-cotton. A central tube passes through the water tank and carries balance weights to give longitudinal trim.

War.—Contains gun-cotton and the detonator.

The primer of the gun-cotton is contained in a central pocket. The percussion detonator is located in the forward end of the primer case.

The nose contains the firing pin and its mechanism. The firing pin is rendered operative by the action of a small four-bladed propeller on a safety nut.

The nut travels on a thread chased on a pin. Upon entering the water, the safety nut being revolved by the propeller, travels out on the pin until it brings up on the guard on the end of the pin, where it continues to revolve freely.

The construction of the firing mechanism is such that the pin is now operative and upon contact with the target a safety pin is sheared, and the force of the blow, which compresses and trips the firing-spring, causes the firing-pin to strike and explode the detonator.

2.—THE CYLINDER.

Contains the fly-wheel and its gearing, and pockets for depth register and charge of phosphide of calcium.

3.—THE AFTER SECTION.

Contains immersion regulator, impulse movement, immobilizer, and two sections of the shafts. The rear, or tail section, carries the stuffing boxes of the shafts, tiller, and immobilizer rods. The shaft stuffing boxes serve also as thrust-bearings. The rear end of this section is called the tail cone and contains the pitch mechanism and carries the tail frame, fin, rudders, and propellers.

II.

The Howell torpedo has twin-screws driven by the fly-wheel whose axis is at right angles to the longitudinal axis of the torpedo. The propellers have adjustable blades, the pitch of which, by means of the pitch mechanism, is made to constantly change dur-

ing a run, increasing as the speed of the fly-wheel decreases. The ratio of the propeller revolutions to wheel revolutions is as 4 to 5.

There are two rudders. The horizontal rudder steers the torpedo up or down. The vertical rudder is for the purpose of keeping the torpedo on an even keel, and insures its rectilinear direction in a horizontal plane. "By virtue of the gyroscopic force of the fly-wheel an exterior force acting on the torpedo and having a tendency to direct it from its horizontal course will simply cause the torpedo to roll, and the motion that is then given to the V. R. will cause the torpedo to roll back in the opposite direction, and will eventually bring it to an even keel.

This curious property of the torpedo may be readily exhibited in the shop by spinning up the fly-wheel, and then striking the torpedo a sharp blow on the nose. Instead of moving laterally as might be expected, the torpedo will simply roll over.

The propeller shafts are parallel and are geared with the fly-wheel. The rudders have tiller-rods which extend into the after section, where they are connected with the "impulse movement."

III.—The Immersion Regulator and Impulse Movement.

In the port side of the torpedo, in the after section, is fitted a flat piston. This piston is held in its outward position by the tension of the immersion spring. The tension varies with the depth at which it is desired to run the torpedo, and is set by hand, access to the immersion spring being had on the starboard side.

The principal feature of the immersion regulator is the "angle guide." This device is shown in Figure 1. *S S* are two very light flat springs. The angle guide is mounted on the piston rod in such a manner that when the piston rod moves in or out, the angle guide will be tipped one way or the other. It is connected with the H. R. pendulum by an adjustable lever.

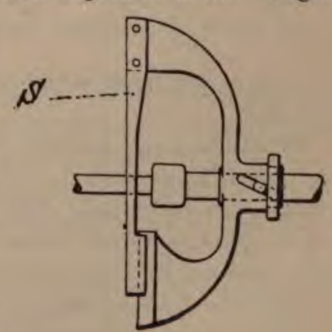


FIG. 1.

The H. R. pendulum swings on a knife edge fixed in the bracket at the top of the torpedo. The V. R. pendulum is located on the port side of the torpedo.

It is by the swing of the H. R. pendulum when the torpedo is diving or ascending, and by the motion of the piston when the torpedo is above or below the set depth, that the position of the angle guide is determined, which thereupon transmits, by means of the impulsive movement, the proper throw to the H. R.

Movement of the piston will tip the angle guide, so also will movement of the H. R. pendulum, and the latter dominates the force exerted by the piston, as will be seen later on.

The mechanism of the impulse movements consists of two racks *T T* (see Fig. 2) sliding in a frame with reciprocal motion simultaneously approaching each other and receding. The motion is derived from two eccentrics which themselves take motion through gearings from worms on both shafts. These impulses are very rapid, usually 4½ per second; the number depending, of course, upon the speed of the shaft, and are continuous as long as the shaft revolves.

These movements or impulses act upon the rudder in this way: The tiller rods have attached to them the little arms or "pallets," *P P* (Fig. 2). These pallets are pivoted at the center. On one

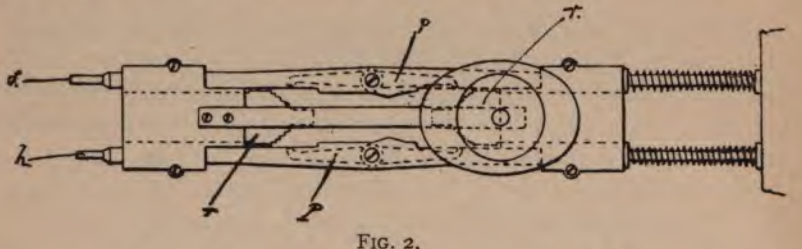


FIG. 2.

end is a pin upon which rest the light springs of the "angle guide."

When the angle guide is tipped by the motion of either the piston or H. R. pendulum, or both, acting together or against each other, the pallet will also be tipped and the toe of the pallet coming in the path of the rapidly moving impulse rack will engage the teeth on the rack, and thus the tiller rod be pushed either forward or to the rear, transmitting motion to the horizontal or diving rudder. In a similar way the V. R. pendulum actuates an adjustable V. R. angle guide, to control the V. R. pallet in reference to the upper impulse racks.

It is clear that as long as the torpedo is moving at set depth with its horizontal axis in the plane of the horizon, the pallets also will be in the same plane, and the impulse racks will travel to and fro without coming into contact with them. There will be no move of either piston or pendulum.

Suppose, however, the torpedo is *above* the set depth. The pressure on piston being less than spring tension, the piston will be set out, the angle guide will tip and engage the forward end of the pallet with the impulse rack, and produce a certain amount of *down* rudder, causing the torpedo to dive. The pendulum then swings forward, and in doing so tips the angle guide in the opposite direction, which engages the *after* end of the pallet in the impulse rack, causing *up* rudder, thus checking the dive. The pendulum's influence being thus greater than that of the piston, this result is obtained, otherwise the torpedo would continue to dive.

If the torpedo is *below* set depth and approaching it, the reverse action takes place.

IV. The "immobilizer" is a rod which has longitudinal motion given by the pitch frame. It holds the pendulum forward or back as desired (when the torpedo is launched) a short interval of time, about two or three seconds perhaps. It will be seen that by holding the H. R. pendulum forward, the angle guide will tip the after end of the pallet to engage the impulse rack, thus producing up rudder. In this way the torpedo's dive is checked. The H. R. pendulum is automatically released at the set time.

V. The torpedo is ejected from the tube (above water) by a 5 to 6-oz. charge of black powder, this being sufficient to throw the torpedo clear of the ship's side.

VI. The fly wheel is spun up by means of a small steam motor which is readily disconnected from the torpedo. The energy in the wheel at 10,000 revolutions per minute is equal to 500,000 ft. pounds, and it requires 30 horse power for one minute to *store* it, but it requires only ¼ H. P. to keep the wheel at 10,000 *after* it has been spun up.

The range of the torpedo is 800 yards; its speed over 400 yards 26 knots. This is the maximum yet attained with the torpedo of 14.2 inches diameter.

U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.

MARCH 21, 1895.

LIEUTENANT COMMANDER B. F. TILLEY, U. S. Navy, in the chair.

THE SOLAROMETER; A MODERN NAVIGATING INSTRUMENT.

By LIEUTENANT W. H. BEEHLER, U. S. Navy.

The great progress that has been made in naval architecture and marine steam engineering demands improvement in the instruments for navigating the magnificent products of human ingenuity as exemplified in the modern men-of-war.

The solarometer claims to meet this demand by providing a method of making astronomical observations independent of the visibility of the sea horizon.

The primary object of the solarometer is this feature of its artificial horizon, which is so combined with the astronomical values of declination, hour angle, azimuth and altitude in relation to the observer's latitude and zenith that all the elements of the nautical astronomical problems are solved.

The mechanical solution of the problem as in the solarometer becomes more of a practical necessity as a result of hourly opportunities to astronomically determine the ship's position and compass errors; not because of any defects in the mathematical computations from altitude by the sextant, but in order to save the time these calculations involve.

If observations were taken once or twice every hour, they would involve a total of from six to eight hours daily work with sextant, alidades and logarithms to obtain the results of those observa-

tions, and this total time would be so distributed throughout the 24 hours that there would be very few spare minutes left for the navigator to do anything else than observe and calculate the results of his observations.

The solarometer obviates elaborate logarithmic calculations and combines in itself a pelorus; so that it furnishes a complete solution of the entire problem to ascertain ship's position and compass errors in the space of time ordinarily required to observe the altitude by the sextant and take its bearing with a pelorus.

The general principles upon which the solarometer is constructed may be concisely stated to consist of a series of circles representing the nautical astronomical triangle supported upon a constant level base which locates the position of the observer's zenith in that triangle.

There is a definite relation between all the five quantities of declination, latitude, hour angle, altitude, and azimuth, such that with each and every variation of the value of one or more of these quantities, the others have corresponding values. The variations of all these quantities cause an infinite variety of possible values to the astronomical triangle, and all are beautifully illustrated by the solarometer.

The Nautical Almanac gives the right ascension and declination of a heavenly body on a circle which passes through the poles. The book of azimuth tables for the same time and place gives the position of the same body or a circle which passes through the observer's zenith. These two publications give the exact position of the same body on two different circles for the same time and place. If the body is on two circles at the same time it must be at their intersection, and if a telescope be fixed at this intersection of the circles representing those of the astronomical triangle, it follows that a body cannot be seen in the axis of that telescope without making this system of circles show the hour angle, elevation of the pole and azimuth, or the observer's longitude, latitude and the ship's compass errors.

This is not a new principle in astronomy but merely a novel point of view, involving a mechanical movement in unison of two variable systems of coordinates, viz.: declination and hour angle, with latitude and azimuth, having their junction marked by the body's zenith distance or altitude. The axis of the telescope lies in the

radius of the concentric circles, and that radius makes an angle with the artificial horizon equal to the altitude of the body observed. This mechanical arrangement of the circles is such that the movement in unison of the declination circle around the poles with the azimuth circle around the zenith makes the axis of the telescope follow the apparent path of the heavenly body observed in the sky from its rising, to the meridian, to setting.

The solarometer is an instrument mounted on a constant level base so arranged that the motion of the ship will not be communicated to the instrument. The constant level base consists of a metal stand about 30 inches in diameter and 4 feet high, with

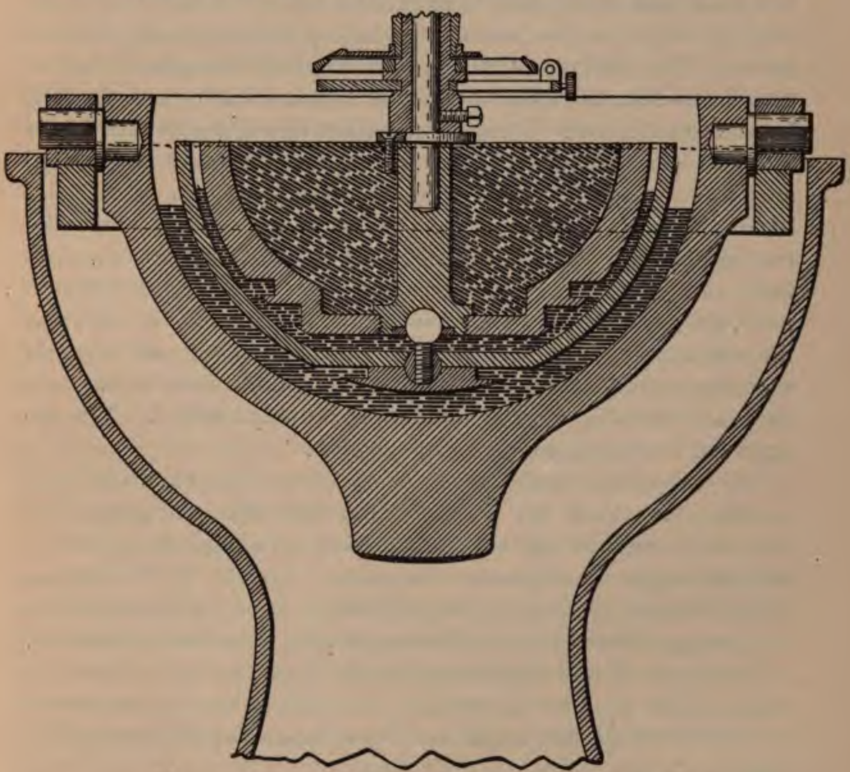


FIG. 1.—Section of standing bowls, float and mercury.

openings underneath to admit an electric storage battery and other implements. On top within the stand there is supported a large

cast iron bowl on gimbals with a forged steel ring. The cast iron bowl is hemispherical. The bottom of the bowl has an extra mass of metal cast with it so as to make it swing on its gimbals with a pendulum effect. The bowl is lined with porcelain and contains mercury and a float. The float is made in two parts and consists of two cast iron bowls, concentric hemispheres. The inner bowl is filled with lead and carries a steel column, rigidly secured at the centre of the bottom of the float and accurately fitted at right-angles to the flat surface of the bottom of the inner float. This steel column projects three inches above the horizontal plane of the top of the bowl. In the center of the bottom of the inner float there is a small spherical recess to admit the ball of a ball-and-socket bolt by which the two bowls constituting the compound float are joined. The bottom of the outer bowl of the compound float is also flat and has a socket in its center to admit the lower ball of the ball-and-socket bolt. The bottom part of this socket is closed by a wrought iron plate whose exterior surface completes the spherical shape of the bottom of the compound float leaving a rectangular horizontal space in the bottom. There are two sets of horizontal rectangular spaces in the sides of the inner bowl of the compound float. All of these horizontal rectangular spaces in the different parts of the compound float are made accurately at right angles to the steel column in the center of the inner bowl, with the object of securing a horizontal flotation of the compound float in the mercury and carrying the steel column absolutely vertical. The instrument is carried upon the steel column.

The experience with the solarometer on the American mail steamer New York has demonstrated that this arrangement of the compound float will not operate on board of high powered vessels, where the vibrations are excessive. In the North German Lloyd steamer Weimar all the vibrations were compensated by this arrangement of floats united together by a ball-and-socket bolt.

The object of making this compound float was to increase the weight of the float by the mercury it contained and to compensate for the vibrations that might be communicated to the mercury in the outer bowl.

It was plainly evident that when the mercury in the outer bowl was agitated as much as the surface of water when boiling the various impulses coming from the agitated mercury were communi-

cated to the inner bowl and gave that bowl a tendency to move in all directions at the same time, and it therefore did not move in any. Any one who agitated the surface of the mercury in the outer bowl would see that the mercury in the inner bowl was not disturbed, and be convinced.

But these concerned only the effect of the vibrations horizontally while the effect vertically remained to be seen by actual experience when mounted on a high powered steamer with excessive vibrations.

By examination and experience on board of the steamer New York on a run from New York to Newport News, on January 20, 1895, the vertical vibrations were found to be communicated to the float with double effect.

The impulses vertically upward appear to be fully annulled by freely rising against the air, but the impulses downward instead of meeting each other in their course along the curved spherical sides of the float and bowls and becoming neutralized, because equal and opposite, met the ball-and-socket bolt and imparted motion to it.

The ball-and-socket bolt was more or less inclined from the vertical and the vibrating impulses coming down on one side met that bolt sooner than those which came down on the opposite side. This bolt then received the successive shocks on one side and alternately received the shocks on the opposite sides. The bolt then communicated all these shocks to the float with double the effect.

These shocks were irregular and made it impossible to determine when the sun or star was in the axis of the telescope for a period of 20 seconds of time.

The ball-and-socket bolt was removed, the vibrations were absorbed and the objects seen in the telescope no longer jumped across the field of view. Before the bolt was removed the inner float had a constant tendency to revolve in the bowl so that the bolt, upon receiving these vertical pressures, acted somewhat like a rudder.

The special function of the ball-and-socket bolt is obtained by small balls or rubber tubing floating on the surface of the mercury. Larger balls are also floated upon the mercury of the outer bowl. These balls keep the float and inner bowl nearly concentric; they do not carry any of the shocks due to the vibrations and they

avoid the sudden send of the float when the ship strikes a huge wave in a heavy sea. The ball-and-socket bolt will no longer be used.

This arrangement of the float in the gimballed bowl provides not only for preventing the motion of the ship from being communicated to the instrument, but also insures the instrument being carried absolutely vertical. The gimballed support of the outer bowl and its pendulum motion compensates for most of the motion due to the rolling and pitching of the ship. The vibrations caused by the throbbing of the engines are absorbed by the mercury in the inner bowl.

The principle involved by using a float in mercury is that which Prof. Michelson used in his apparatus to determine the velocity of light. He claims that the truest level that can be obtained under any circumstances for accurate astronomical work is that secured by floating a block of granite in a tank of mercury.

The float is free to move about in the mercury. The top surface of the inner part of the float is covered with a compass-rose, marked to quarter points and graduated in degrees from zero at north to 180 degrees south in each hemisphere. The top edge of the outer bowl is marked with lubber lines indicating the plane of the ship's keel. At these two points in the plane of the keel of the ship, or parallel therewith, are two pointers, which are hinged and lightly rest upon the compass-rose to indicate the direction in which the ship is headed.

As the compass-rose on the inner float will be carried about so that its center will rarely ever be exactly coincident with the center of the bowl, it is necessary to note the position of the pointers of the lubber line and transfer the plane of the lubber line to the plane passing through the center of the float as is explained by reference to the diagram of the compass-rose which contains the following instructions: "At the instant of an observation, note the points of the compass-rose that lie in the plane of the ship's keel, or of the lubber line.

"If diametrically opposite points are in that plane, the forward point will show the true direction in which the ship is heading at that instant. If the plane of the lubber line passes through points not diametrically opposite, apply to the forward point the half difference between 180 degrees and the sum of those points in de-

grees. This corrected reading of the forward point will be the true direction of the ship's head."

Owing to the peculiar notation of the degrees on this compass rose constantly increasing from zero to 180 degrees from left to right, and then decreasing to 170 degrees on the other side, there is an apparent exception to the rule. For instance, in case the

FIG. 2.—The compass-rose of the Solarometer at the instant of an observation of the sun or a star has its north point exactly in the direction of the true north.

lubber line should pass through a line north 10 degrees east and north 175 degrees east, the half difference between 180 degrees and the sum of these two points would be $2\frac{1}{2}$ degrees ; and the

forward reading would be north $7\frac{1}{2}$ degrees east, and the after reading would be north $177\frac{1}{2}$ degrees east. These are evidently not diametrically opposite points. In this and similar cases, where the plane of the lubber line runs nearly north and south, one point should be read north so many degrees east, and the other north so many degrees west, or in this instance one would be read north 10 degrees east and the other north 185 degrees west, and according to the rule, half the difference between 180 and 195 degrees, or $7\frac{1}{2}$ degrees, would give the ship's head; in this case, north $2\frac{1}{2}$ east. The compass-rose has the figure 190 on the inner circle opposite 170, to indicate where the notation should be greater than 180 degrees, and the rule given on the compass-rose is thus made to apply under all circumstances.

The spherical shape of the bowls and float has a beneficial effect in compensating for the motion of the ship. The rolling and pitching makes the bowl move around the mercury. The weight of the mass of mercury, its consequent inertia, and the almost frictionless contact it makes with the porcelain surfaces tend still further to keep the mercury at rest. The shape of the displaced volume of mercury in the outer bowl is spherical, no matter how the bowl may move around the mass of mercury, and hence all currents that might be otherwise set up in the mercury are obviated, and the use of mercury is peculiarly well adapted for this purpose. It must be remembered that the bulk of the motion of the ship is compensated by the gimballed support of the bowl, and the percentage of that motion remaining to be compensated by the mercury is very small.

The only motion of the ship that cannot be compensated is that due to yawing or bad steering. Practice at sea, however, will soon enable an observer to follow that motion by swinging the float correspondingly. With the vibrations due to the engines there is an effect upon the observer's eye which causes the image of the body observed to oscillate slowly in the field of the telescope. In the American Line steamer New York the solarometer was mounted on a light steel deck within six feet of a windlass on the same deck. The vibrations of that deck when that windlass was in operation were extremely violent, but the image of the sun's disc always remained perfectly clear and well defined, but the disc moved about $\frac{1}{8}$ of its diameter back and forth across the

cross-hairs in the telescope, requiring a little judgment to determine when the disc was in the axis of the telescope. On one occasion, in the U. S. S. Montgomery, a simple float without the extra bowl and inner mercury was used, and then the vibrations of the engines at times made the sun's disc so indistinct that it could not be observed.

In taking observations, the float is necessarily disturbed by handling the instrument, but it soon comes to rest, and the evidence that it is at rest is plain from the observation of the heavenly body at rest in the telescope. In the first designs of the instrument, the horizon circle had eight spirit-level bulbs counter-sunk in the metal, but the inertia of the spirit bulbs was such that they continued to oscillate after the body observed was seen to be perfectly at rest in the telescope.

The instrument mounted on the constant level base consists of five circles with a supporting bracket and a telescope. The five circles represent the meridian, equator, declination, horizon, and latitude.

The meridian circle M and the equatorial circle E are joined rigidly at right angles to each other, and each has a pair of trunnions at points 90 degrees from their junctions. A hemispherical bracket A, with a hollow cylindrical sleeve, fits on the vertical spindle of the float and has bearing plates in its upper extremities to receive the trunnions of the equatorial circle E. These bearings are adjustable vertically and laterally by means of adjusting screws underneath and on the side of the bearing blocks. The trunnions of the equatorial circle E are diametrically opposite at 6 hours or 90 degrees from the plane of the meridian circle. It is graduated into hours, minutes, and to 30 seconds of time from zero to 12 hours on each side of the meridian.

One of the equatorial trunnions is hollow to admit a tube that projects inward and carries two horizontal arms with vernier plates to lie against the graduated surface of the meridian circle M. A pendant arm is attached to the outer end of the tube carrying these verniers, and has near its lower end bearings against two adjusting screws fixed within the frame of the supporting bracket A. On the opposite side there is a vise-clamp to secure the trunnion of the equatorial circle E in any fixed position. A pendant arm on this trunnion fits in between the frame of the bracket A,

and abuts against a spring and micrometer screw to permit small movement of the clamped trunnion and to accurately set the equatorial and meridian circles to any desired elevation of the pole of the meridian circle *M*.

The meridian circle *M* is graduated to degrees, minutes and seconds of arc, from zero to 90 degrees in each quadrant.

The declination circle *D* is concentric with the meridian circle *M* and revolves on the trunnions at the poles around the equatorial circle *E*. This circle is graduated into degrees, minutes and seconds of arc. It carries a covering ring that supports the opposing verniers on the graduated face of the declination circle. A sliding block on the circle carries the verniers 180 degrees apart. A block with set screw and tangent screw permits accurate setting of the declination verniers at any desired point. The graduations are from zero at the equator to 90 degrees at the poles.

In the radial plane of the zero of the upper declination vernier block there is a socket tube which receives a pendant pin from the telescope block on the bracket *K*.

The declination circle revolves around the poles of the meridian circle and over the face of the graduated equatorial circle *E*. Two verniers are attached to the sides of the declination circle, on opposite side of the equatorial circle. These verniers fit close to the graduations of the equatorial circle and enable those graduations to be read to one second of time. The notation of the graduated equatorial circle is such that the zero of the vernier on one side of the declination circle comes opposite the mark for 12 hours when the vertical plane passes through the meridian circle and the common center of all. The numerical notation of the graduation is simply slewed around to accommodate the space required for the metal of the declination circle.

A graduated horizon circle is attached to the bottom of the cylindrical sleeve of the supporting bracket *A*. Above this circle a hemispherical bracket *B* revolves around that sleeve and carries two flat arms with opposing vernier plates to move over the graduations of the horizontal circle *Z*. The upper extremities of the hemispherical bracket *B* have bearing shafts supporting the hemispherical bracket *K* which revolves vertically from the horizon to the zenith, at the same time that the supporting bracket *B* revolves around the horizon circle *Z* at the bottom of the instrument.

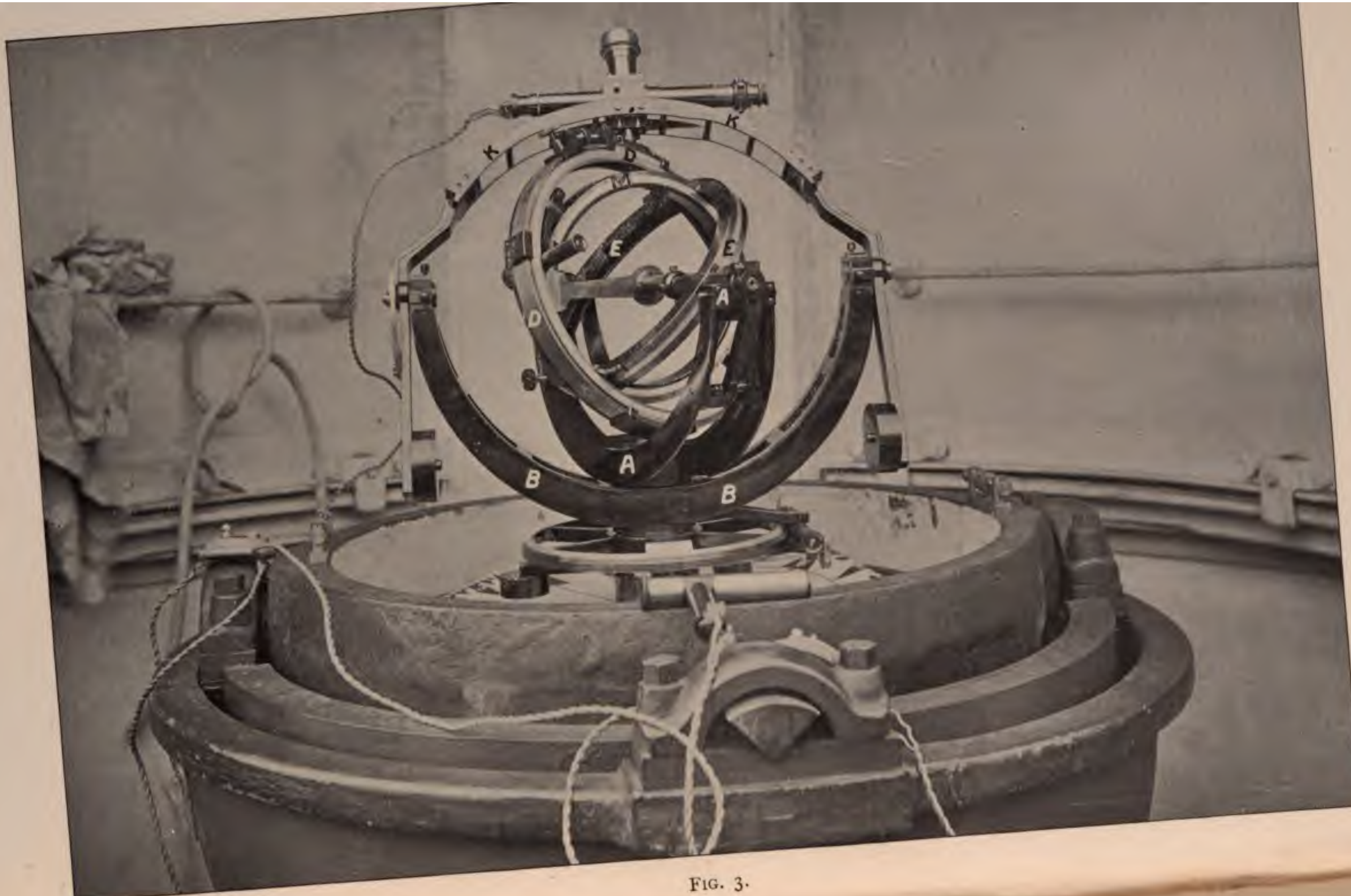


FIG. 3.

king the several circles combine to cause the axis of the telescope in its motion to point and follow the apparent path of the heavenly body that may be observed in the sky.

All the bearings and movable parts of the instrument are adjustable. All the graduations are on silver, and each circle has opposing verniers, so that if there be any eccentricity it may be eliminated by taking the mean of the readings of the two verniers.

The circles are made of composition gun-metal ; they are channel-barred with strengthening blocks at junctions. The instrument is as light as possible consistent with the requisite strength for durability.

In the earlier designs, the instruments were made of alloyed aluminum. Different alloys were tried and none were found to be suitable. At sea the aluminum seemed to absorb salt from the air ; at least small white crystals were found on the rings every day, while none could be seen on the yellow metal of certain parts. The oxidization of aluminum is white, and these crystals may have been particles of oxidized aluminum, but they had a salty taste, were easily removed, and were found in greater quantities at sea than in port away from the sea air. The hard silver aluminum alloy was also found to be too soft for the bearings, and it was necessary to bouch the bearings in that metal in the shop after the limited use of the instrument for observations in Fauth & Co's yard in Washington. Experiments were made with various aluminum alloys in a simple salt water bath, and after three months in the bath they were pitted as much as a zinc rod in a Le Clanchè cell, with a year's service. This experience has conclusively demonstrated the worthlessness of such alloys of aluminum as were tried, for any instrument of precision. The weight of the solarometer made of aluminum alloy was 21 pounds, or only 7 pounds less than the weight of the present channel-barred composition gun-metal instrument.

In making the broad statement that an observer can accurately determine a vessel's position and compass error by the solarometer at all hours when anything is visible in the sky, there are certain limitations. It is not claimed that anything can be done with the solarometer which may not be solved by mathematics.

In observing bodies on the prime vertical when the effect of an error in the latitude has but little or no apparent effect on the

computed hour angle, it will be extremely difficult to find the latitude by the solarometer at such a time, and in the same manner the time and azimuth will be extremely difficult to determine accurately by observations of a body crossing the meridian near the zenith.

As the solarometer must be supported at some point on the equatorial or meridian circle, it has been found to be least disadvantageous to support it at six hours from the meridian. These supports prevent observations from being taken at these hour-angles, but as the altitudes will be low and the effect of refraction large, the time is unfavorable.

But these limitations do not apply if the body is at any appreciable distance from those directions, and the times when the observations of visible bodies are not advantageous are comparatively so few that, generally speaking, the broad statement ought to be admitted.

To use the instrument the observer has a chronometer regulated to Greenwich mean time, a nautical almanac, book of azimuth tables, refraction tables, and blank record books with forms for observations of the sun and stars.

METHOD OF OBSERVING.

For Observations of the Sun.—Find in the nautical almanac the sun's declination and equation of time for the Greenwich time of the observation, adjust the vernier of the declination circle *D* to the declination for the Greenwich apparent time. Set the latitude vernier to the approximate latitude of the place. Point the telescope to the sun by revolving the telescope arm and bracket to its altitude, and swing the float in the bowl, to find the sun's disc in the axis of the telescope. The axis of the telescope should be set a little west of the sun, and the instrument allowed to come to rest on its float while waiting for the sun to move westward in azimuth and altitude to appear in the exact axis of the telescope. Note the time by chronometer (or watch compared with the chronometer regulated to Greenwich mean time) the instant the sun is in the axis of the telescope. The arrangement of cross hairs circumscribing the sun's disc enables the observer to readily determine when the center of the sun's disc is exactly in the axis of the telescope. At the same instant the position of the pointers in

the plane of the lubber line must be noted on the compass-rose of the float. Read the hour angle and azimuth to record the observation.

OBSERVATION OF THE SUN.

NORTH GERMAN LLOYD S. S. WEIMAR.

Observer, Mr. C. NAHRATH, 2d Officer. Date, *August* 19, 1894.

	h.	m.	s.		m.	s.
Chronometer,	5	02	12	Chronometer Error,	—3	42
Watch,	1	15	0	Change by Rate,		—1
Chronometer—Watch,	3	47	12	Chronometer Correction,	—3	43

Sun's Declination, N.			H. D.	Equation of Time,		H. D.
°	′	″	″	m.	s.	s.
12	42	28	—49	3	26.7	—.58
	—4	5	5		—2.9	5
12	38	23	—245	3	24	—2.90

	h.	m.	s.
Watch Time,	1	21	44
Chronometer—Watch,	3	47	12
Chronometer Time,	5	8	56
Chronometer Correction,		—3	43
Greenwich Mean Time,	5	5	13
Equation of Time,		—3	24
Gr'nw'h Apparent Time,	5	1	49
Local Apparent Time,	1	24	52
Longitude,	3	36	57
	°	′	″
Longitude in Arc,	54	14	15

Remarks :

Forward Index A = N 80° E.

After Index B = N 110° W.

2) — 10 = 180 — 190

—5 + A = N 75° E = True Course.

N 80° E Comp's Course.

5° Comp's Error.

VALUES BY SOLAROMETER.				BY TABLES.		
		°	′		°	′
Latitude,		40	58		40	58
	°	′	″	°	′	″
Declination,	12	38	23	12	38	23
	h.	m.	s.	h.	m.	s.
Hour Angle,	1	24	52	1	24	52
	°	′		°	′	
Azimuth,	140	40	W	140	40	W

State of Weather, Pleasant. Wind Direction and Force, N. W. 5.
State of the Sea, Smooth. Degrees of Roll each Way, 4. Pitching, 2.
Visibility of Sea Horizon, Clear.
Ship's Position by Dead Reckoning: *Latitude*, 40° 58′ N. *Longitude*, 54° 18′ W.
Ship's Position by Sextant: *Latitude*, 40° 58′ N. *Longitude*, 54° 15′ W.

This observation with an assumed latitude is a correct altitude of the sun's center, but the hour angle would be in error corresponding to the error in the assumed latitude, precisely as in an ordinary time sight taken with a sextant if worked with an erroneous latitude. When the latitude is not known, it is therefore necessary to take a series of observations to determine both the latitude and hour angle, or the true local apparent time. Proceed then to take a second observation, setting the latitude 10, 20, or 30 minutes (according to the amount in which the latitude may be in doubt) north of the latitude used at the first observation, and take a second observation as before, noting the chronometer time, hour angle and azimuth for record. After recording, take a third observation, setting the latitude 10, 20, or 30 minutes south (according to the amount in which the latitude of the first observation may be in doubt) of the latitude used in the first observation, note the chronometer time, the position of the pointers of the lubber line at the instant of the observation, and read the hour angle and azimuth for record. The three observations with these different latitudes must then be compared to determine the true latitude.

Take the difference between the chronometer times of the first and second observations and the difference between the solarometer hour angles of those observations; find the second difference between these two intervals.

Take the difference between the chronometer times of the first and third observations and the difference between the solarometer hour angles of those observations; find the second difference between these two intervals.

Take the difference between the latitudes of the second and third observations, or the difference between the extreme latitudes used.

We then have the proportion that, as the sum of the second differences is to the second difference of the first and second observations, so is the extreme difference between the latitudes used to the correction to be applied to the latitude used for the second observation. Similarly as the sum of the second differences is to the second difference of the first and third observations, so is the extreme difference of latitude used to the correction to be applied to the latitude used in the third observation.

Each of these proportions will give the true latitude. Proceed to take a fourth observation, using the true latitude thus found to find the true hour angle. In every case note the change in latitude due to the ship's run in the interval of observing and make proper allowance for that change.

The following series of three observations by the solarometer will explain this subject clearly.

	Chronometer Time.	Hour Angles.	Latitude used.
1st observation....	10 h. 7 m. 35 s.	11 h. 21 m. 20 s.	38° 55′ N.
2d observation....	10 h. 10 m. 19 s.	11 h. 28 m. 30 s.	39° 10′ N.
3d observation....	10 h. 14 m. 57 s.	11 h. 22 m. 5 s.	38° 30′ N.

Comparing the first and second observations, the difference between chronometer times equals 2 m., 44 s., or 164 s., and that of the hour angles equals 7 m., 10 s., or 430 s.; the difference between these intervals is 430 s. — 164 s., or 266 s.

Comparing the first and third observations, the difference between chronometer times equals 7 m. 22 s., or 442 s.; that between the hour angles 45 s.; and the difference between these intervals is 442 s. — 45 s., or 397 s. The sum of the second-differences is $266 + 397 = 663$.

We have then the proportion that, as the sum of the second differences is to the difference of intervals of the first and second observations, so is the difference between the highest and lowest latitude used to the correction to be applied to the latitude used in the second observation; or, as the sum of the second-differences is to the difference in the intervals of the first and third observations, so is the difference between the highest and lowest latitudes used to the correction to be applied to the latitude used in the third observation.

In this example we have the two proportions, viz.:

$$663 : 266 = 40 : 16'; \text{ and } 39° \ 10' - 16' = 38° \ 54'.$$

$$663 : 397 = 40 : 24'; \text{ and } 38° \ 30' + 24 = 38° \ 54'.$$

In this example, the latitude used in the first example was nearly correct, and it will be noticed that when, as in the second observation, the latitude was too high, the difference between the solarometer hour angles was greater than that between the chronometer times. And again, when the latitude used is lower than the true latitude, as in the third observation, the difference be-

tween the solarometer hour angles is less than that between the chronometer times.

It follows as a rule that in any series of observations of the same body, if the difference between the solarometer hour angles is greater than that between the chronometer times the latitude used is too high; and if the difference between the solarometer hour angles is less than that between the chronometer times the latitude used is too low.

By keeping this rule in mind, a skillful observer will soon be able to discover error in the assumed latitude and find the correct latitude and the corresponding correct hour angle readily.

Having found the latitude, take a fourth observation with that latitude and find the hour angle as before, which will be the exact local time. These four observations, which can with practice readily be taken in 10 or 15 minutes, determine with an accuracy within two miles the observer's latitude and local apparent time, and hence his longitude; and by comparing the compass course at the instant of the last observation with that indicated by the lubber line on the compass-rose of the solarometer, the error of the compass on that course will be accurately ascertained.

This method of determining the latitude and hour angle is based upon the fact that by the movement of the telescope in altitude and azimuth, the altitude is affected by the elevation of the the pole and the distance of the telescope from the meridian. If the latitude is too high or too low, the movement of the telescope will not follow the plane of the path of the movement of the body in the sky, but will incline thereto, either higher or lower, according to the error in the elevation of the pole, or the latitude used, and the differences between the chronometer time interval and the solarometer time interval, indicated by the hour angles, show the deviation of the movement of the telescope from the plane of the path of the body in the sky.

Another method for determining the latitude and hour angle is to take one observation with an assumed latitude, and then take a second observation at five or ten minutes later; if the hour angles differ exactly five or ten minutes, then the assumed latitude is the true latitude. If they differ unequally, set the latitude north or

south accordingly; take a third observation, and five or ten minutes later take a fourth observation; if the chronometer time intervals and the difference between the hour angles of the third and fourth observations are the same, the latitude last used is correct, and so is likewise the hour angle of the last observation. If the chronometer time intervals and hour angle intervals of the third and fourth observations do not correspond, correct the latitude again, corresponding to the difference, and take two more observations, and proceed in this manner until both the latitude and hour angle are correctly obtained.

In taking and reading the observations, the opposing verniers should generally both be read. If there is any discrepancy between the readings of the two opposing verniers on the same circle, the mean of the two must be taken to eliminate any eccentricity caused by dust, etc., in the bearings around which the circles revolve.

In taking observations of the sun at low altitudes, it is necessary to allow for refraction. A clinometer is attached to one prolonged arm of the telescope bracket *K* to indicate the angular altitude of the axis of the telescope. Refraction causes the sun to appear higher than it really is, and the observer should observe the center of the sun in its true position and not in the position where it appears elevated by the refraction of the atmosphere. Tables showing the effect of refraction at various altitudes are given in the books of navigation, but in observing with the solarometer the observer may apply this correction in the altitude when observing, and to do this, he must observe a star or the center of the sun's disc as much below the axis of the telescope as the refraction makes it appear above its true altitude. The small central square in the axis of the telescope is a square whose dimensions are equal to two minutes and forty seconds ($2' \, 40''$), which is the refraction for an altitude of 20 degrees. One half of that space is the refraction for 36 degrees, and two spaces would be the refraction for an altitude of 10 degrees. The clinometer shows the altitude approximately; and, with practice, a skillful observer can allow for the effect of refraction at different altitudes and varying conditions of the atmosphere.

This method of observing the sun or a star as much below the

axis of the telescope as the refracted rays of light make it appear above its true position is theoretically correct, but it is difficult to introduce into practice.

When the amount of the refraction is known, it is much more difficult to allow for it than to observe the body exactly in the axis of the telescope, and the effect of neglecting or accurately allowing for the refraction is much greater than is generally supposed. The habit of applying refraction to observed sextant altitudes is so fixed that the effect of neglecting it has not been generally considered by practical men.

Tables are in preparation showing the effect of refraction on the hour angle at different altitudes for different latitudes and polar distances. These tables have so far been completed only for the latitudes of the transatlantic steamer routes, and they show regularity in the decreasing error of the hour angle up to within a certain azimuth, when the error begins to increase and reaches a second maximum close to the meridian.

This peculiarity is explained by the fact that the change in altitude is greatest on or near the prime vertical, and that when on or near the meridian, it takes the body much longer to change its altitude by the small amount of the refraction, than when nearer the prime vertical to change very much more in altitude.

The table for a latitude of 40 degrees north, polar distance of 100 degrees, shows an error of 30 seconds in time at an altitude of 10 degrees, when the hour angle read from the solarometer was 4 hrs., 31 min., 8 sec., without allowing for refraction of 5′ 20″, azimuth 112° 33′ instead of 112° 29′. At an altitude of 20 degrees, azimuth 123° 5′, the hour angle was 16 seconds too small. At an altitude of 30 degrees, azimuth 138° 11′, the hour angle was 12 seconds too small. At greater altitudes the error in the hour angle began to increase until at an altitude of 39 degrees, azimuth 166° 14′, it was 18 seconds too small; 43 min., 22 sec., from the meridian instead of 43 min., 40 sec. The error in hour angle near the meridian is much greater and in a measure indeterminate.

Observations for time, on or near the meridian are not reliable, especially under these circumstances, and the effect of refraction must then be considered almost entirely upon the latitude.

By setting the declination at a polar distance decreased by the refraction multiplied by the cosine of the hour angle, a fair degree of accuracy will be obtained by observing the body in the axis of the telescope to find the latitude on or near the meridian.

In using these tables, the observer notes the chronometer time when the body is exactly in the axis of the telescope and the position of the plane of the lubber line on the compass-rose. He then reads the azimuth, hour angle, and altitude from the clinometer attached, and corrects the hour angle for the refraction according to the correction given in the tables. He then sets the declination circle to the correct hour angle and finds the true azimuth corresponding thereto from the azimuth circle. The difference between the azimuth observed and the correct azimuth must be applied to the compass-rose to find the corrected heading of the ship.

In finding both latitude and longitude from a series of observations by second differences, each of the observations should be corrected and second differences worked from the corrected hour angles to find the true latitude, as explained.

The effect of parallax is so small that it is ignored in observations by the solarometer; observations of the moon are not recommended on account of its horizontal parallax.

OBSERVATIONS OF STARS.

For observations of stars, a small electric lamp shining through frosted glass, illuminates the cross hairs in the eye-piece without affecting the clear visibility of the star in the telescope. The magnifying power of the telescope is such that the usual bright navigational stars are clearly distinguishable, more so than with the naked eye.

OBSERVATION OF ALTAIR.

NORTH GERMAN LLOYD S. S. WEIMAR.

Observer, Lieutenant W. H. BEEHLER, U. S. N. Date, *August* 26, 1894.

	h.	m.	s.		m.	s
Chronometer,	9	52	10	Chronometer Error,	—3	45
Watch,	4	45	0	Rate,		—1
Chronometer—Watch,	5	7	10	Chronometer Correction,	—3	46

*'s Right Ascension,			*'s Declination,			Right Ascension, Mean Sun.		
h.	m.	s.	°	′	″	h.	m.	s.
19	44	40	+8	35	22	10	18	53.2
							1	48
						10	20	41

	h.	m.	s.
Watch Time,	5	56	25
Comparison,	5	7	10
Chronometer Time,	11	3	35
Chronometer Correction,		—3	46
Greenwich Mean Time,	10	59	49
Local Mean Time,	10	47	7
Longitude in Time,		12	42
	°	′	″
Longitude in Arc,	3	10	30

	h.	m.	s.
*'s Hour Angle,	1	23	8 W.
*'s Right Ascension,	19	44	40
R. A. Meridian,	21	7	48
R. A. Mean Sun,	10	20	41
Local Mean Time,	10	47	7

	VALUES BY SOLAROMETER.			BY TABLES.		
	°	′	″	°	′	″
Declination,	8	35	22	8	35	22
Latitude,	50	9	45	50	9	45
	h.	m.	s.	h.	m.	s.
Hour Angle,	1	23	8	1	23	8
		°	′		°	′
Azimuth		150	10		150	11

Forward Index A = N 85° E.
After Index B = N 89° W.
2) +6 = 180 — 174
3 + A = N 88° E = True Course.
N 114° E Comp's Course.
26° Comp's Error.

State of Weather, Pleasant. Wind direction and Force, S. W. 5.
State of Sea, Smooth. Degrees of Roll Each Way, 2. Pitch, 1.
Visibility of Sea Horizon, Undefined.
Ship's Position by Dead Reckoning: *Latitude*, 50° 10′. *Longitude*, 3° 08′.
Ship's Position by Sextant or Bearing: *Latitude*, ... *Longitude*, ...

For observations of a star, find in the Nautical Almanac the star's right ascension and declination, and the right ascension of the mean sun, all of which are to be corrected for the Greenwich time of the observation. Set the declination vernier on the declination circle *D* to the declination of the star, and the latitude vernier to the approximate latitude of the observer. Revolve the telescope in altitude and azimuth, and find the star in the axis of the telescope in the same manner as described for observations of the sun. When the latitude is not known, take a series of observations in the same manner as described for observations of the sun.

The facility with which a star can be found in the field of the telescope is remarkable. It is much easier to find the star to be observed in the field of the telescope than to point a spy-glass to see a star when standing on land, especially if the declination circle is set to the approximate hour angle.

To read the arcs with facility, a small hand telescope is provided in which there is a side tube containing a miniature electric lamp, which throws a light from within the reading telescope through its object lens on the vernier, which is thereby clearly illuminated.

In recording the observations, the four quantities—declination, latitude, hour angle, and azimuth—as read from the solarometer should be compared with those same four quantities in the book of azimuth tables, enlarged and extended. If there is exact correspondence between the observed four quantities read from the solarometer and those computed in the book of azimuth tables, the observer has positive proof that his result is accurate.

For observations of Polaris, or the polar star, note the right ascension and declination of Polaris in the Nautical Almanac, and see if the right ascension is such that the star is above or below the pole. If the star is above the pole, set the declination circle vernier at the north declination 88° 44′ 15″. But if the star is below the pole, set the declination vernier at its sub-polar declination, 91° 15′ 45″, or as given in the Almanac.

If the star's hour angle is not approximately known, it may be readily ascertained by adding the right ascension of the mean sun (as given in the Almanac and corrected for the Greenwich mean time) to the approximate local mean time to find the right ascension of the meridian; then add or subtract the star's right ascension

from the right ascension of the meridian to get the star's hour angle.

As the declination circle revolves on the polar axis the observer must not attempt to revolve the declination circle by means of the telescope bracket or the azimuth clamp when the telescope is clamped by the declination set-screw near the pole. In this position the change in azimuth can be but very small, and the leverage of the telescope bracket is liable to throw the instrument out of adjustment. Any change in hour angle with the telescope near the pole must be made by turning the declination circle in hour angle directly, and allowing the movement of the declination circle to move the telescope bracket *B* in azimuth.

The clamp screw which sets the declination circle at any hour angle ought not to be used for any observations; it is provided for use in adjusting the instrument, and should not be used when taking observations.

Having set the declination of Polaris on the solarometer, and the latitude vernier to the observer's approximate latitude, put the declination circle to the approximate hour angle of Polaris and turn the telescope by swinging the float horizontally until the star is seen in the field of the telescope. Bring the star in the axis of the telescope by working the micrometer screw of the latitude clamp. This will give the altitude of Polaris, and, since the position of the declination circle in hour angle mechanically causes the pole of the solarometer to be as much elevated or depressed from the altitude of the north pole as the star's position in its path around the north pole deviates from the north pole, the pole of the solarometer will have the same elevation as the true north pole, and the vernier on the meridian circle will show the observer's true latitude.

Observations of Polaris by the solarometer have invariably been found to be exact, much more so than any meridian altitude of the sun by a sextant. It is claimed that a good observation of Polaris under favorable conditions will give the true latitude within one mile. Observations of Polaris where cross bearings of lighthouses were available, as in the Chesapeake bay, invariably indicated the latitude as accurately as those by cross bearings, and agreed perfectly.

DETAILS OF MANUFACTURE AND ADJUSTMENT.

In the manufacture of the solarometer all the circles are turned on the lathe and are made absolutely concentric. The equatorial circle *E* and the meridian circle *M*, after being securely united together at right angles to each other are revolved in the same lathe. These circles are graduated after they have been thoroughly tested to be concentric and accurately at right angles to each other. They are placed in the adjustable bearings on the hemispherical bracket *A* and fitted on the lathe. The declination circle is fitted on its polar trunnions and adjusted to revolve around its polar bearings, exactly concentric with the meridian and equatorial circle. The telescope supporting arm *B* is placed on the shaft under the hemispherical bracket *B* and adjusted to revolve concentrically around that shaft. The azimuth circle is fixed rigidly on the bottom of the shaft under these brackets and adjusted to be accurately in the horizontal plane at right angles to the vertical axis passing through the common center of the rings. The telescope bracket is fitted in its bearings on the ends of the hemispherical arm *B* in the horizontal plane passing through the common center of all the rings. The telescope block with its projecting pendant pin is fitted into the socket tube on the declination vernier block, and the telescope block is centered in the telescope bracket *K*. All parts are thus assembled and ready for final accurate adjustment.

APPURTENANCES.

Each solarometer is furnished with a set of implements, viz. :

First.—A reading telescope to be held in the hand. This is designed to be held close to the eye and close to the vernier to be read, and its magnifying power is such that the fine graduations of the verniers are clearly legible and sharply defined. It is made of aluminum and can be readily cleansed. For use at night, a small tube is set in on one side at an angle opening towards the object lens. This tube contains a miniature electric lamp of 1 candle power, 4 volts, and requires 1 ampère current. A small aluminum shield is set in the main tube of the reading telescope and prevents the electric light from being thrown into the observer's eye. The light clearly illuminates the vernier and enables it to be

read with even better facility than by daylight; under circumstances, the observer will find it advantageous to use the electric light in day time. The arrangement is such that the lamp and its shield do not interfere with its use by daylight. All verniers are accessible to the reading telescope in all the various positions of the different circles.

Second.—Two miniature electric lamps are furnished for reserve supply in case of breakage.

Third.—A striding level to fit upon the bearings of the hemispherical arm *A* is furnished for use in adjusting the instrument, to see if it is carried absolutely vertically upon the float.

Fourth.—One spare set of spider cross hairs, and one reticule of cross lines engraved on glass. These reticules are not to be inserted or adjusted unless the vessel's position is accurately established. Though exceedingly delicate, it is rare that it will be necessary to use the spare reticules.

Fifth.—Two shade glasses, which fit over the eye-piece for the observations of the sun.

Sixth.—One screw-driver.

Seventh.—Two small steel capstan bars for making adjustments.

Eighth.—Two electric storage batteries, with suitable lengths of insulated conducting wire, switches, etc. One of these batteries is to be kept underneath, within the stand of the base. The other battery is charged and kept in reserve to replace the one in use within the stand when exhausted.

ADJUSTMENTS.

First.—Adjust the bearings of the equatorial circle *E* on the adjustable bearing on the horizontal plane of the hemispherical bracket *A*. The equatorial circle is placed horizontally, and the meridian circle exactly vertical. The bearings are adjusted with the equatorial circle perfectly horizontal, by means of the adjusting screws.

Second.—Clamp the declination circle *D* accurately in the vertical plane of the meridian circle. Loosen the latitude vise clamp *V* on the hemispherical bracket *A* and revolve the three circles *E*, *M*, and *D*, together in the bearings of the equatorial ring. In revolving, the declination circle *D* must always remain in the vertical plane of the meridian circle *M*, and it is so adjusted.

Third.—Place the declination circle in the plane of the meridian circle *M* with the pin of the telescope set in the declination vernier socket and adjust the telescope block so that the axis of the telescope is equidistant from the bearings of the telescope bracket *K* on the supporting hemispherical arm *B*. Loosen the declination clamp screw and revolve the telescope in altitude from the horizontal plane to the vertical and the horizontal plane on the opposite side, adjusting any deviation of the axis of the telescope from the vertical plane of the meridian circle.

Fourth.—Set the azimuth circle with its opposing verniers at zero and 180 degrees, loosen the declination clamp, and revolve the telescope in altitude, and adjust the bearings for any deviation of the hour angle from the plane of the meridian circle. The declination circle must, in this case, remain in the plane of the meridian circle, though unconfined. Any deviation will be corrected by adjusting the height of the telescope bracket bearings.

Fifth.—Point the telescope to a distant fixed point, and adjust its axes by revolving the loosened verniers and latitude clamps for various positions in the plane of the meridian circle *M*.

Sixth.—Place the instrument upon a level stand on a pier, put the axis of the telescope in the zenith of the instrument. A collimating tube with a cross hair is fixed above the instrument in the vertical plane of the axis of the center of the instrument. By looking in the eye-piece of the telescope, the collimating wire must appear in the center of the cross-hairs in all positions in which the arm *B* may be revolved.*

Seventh.—The circles are set at every 10 degrees of latitude and declination, and every 10 minutes of hour angle ; and for all the various positions which the azimuth circle will occupy due to these combinations, the azimuth must coincide with the computed azimuth in the book of azimuth tables.

Eighth.—The instrument is mounted on a solid pier and observations are made of the heavenly bodies, and adjustments tested.

Ninth.—The instrument is next placed upon the float and se-

*The instruments made by Fauth & Co., Washington, D. C., were adjusted by this firm in the manner described. The sixth adjustment is a very ingenious and satisfactory method devised by this firm, and great credit is due them for the skillful and accurate workmanship of the solarometers they have made.

cured thereon, with the plane passing through the zero and 180 degree points of the azimuth circle, exactly coincident with the plane passing through the north and south points of the compass-rose on the float. A striding level is put upon the recesses in the hemispherical bracket *A* and the instrument is revolved in different positions in azimuth and altitude to determine if it is thoroughly counterbalanced in all of its parts, and is carried absolutely vertical by the float.

Tenth.—The instrument is finally mounted on its constant level base and tested by taking observations of the sun and stars at different declinations to determine the longitude and latitude of the observer, in the yard at Fauth & Co.'s works. The result must be exact.

In the manufacture of the stand, bowls and floats, careful and accurate mechanical workmanship is also requisite. The bearing blocks of hardened steel are accurately fitted, and the forged steel ring and bowl are accurately balanced on their gimballed bearings.*

After the float is floated in the mercury the level flotation is tested by a sensitive spirit level centered on the spindle on which the instrument is mounted. The float swimming in the mercury is revolved, and after it ceases to oscillate the bulb of the long spirit level must come to perfect rest while the float continues spinning in the mercury perfectly horizontal. The long sensitive spirit level is placed in all positions in different horizontal planes on the spindle that supports the instrument, and the level flotation of the float is tested in all positions both at rest and when spinning freely in the plane. All the floats are adjusted to meet these requirements and the accuracy of the constant level base is established beyond all doubt.

Whenever the float is touched by the hands the level flotation is necessarily disturbed, but it comes back with remarkable celerity.

Actual experience is necessary to convince many of the fact that the motions of the ship are thoroughly compensated by the constant level base. When a huge wave strikes the ship, the float will be by its inertia thrown with some degree of violence against the sides of the bowl, but experience thus far obtained has shown that this rarely happens and only interferes with observing for a

*The bases, bowls, floats, and observatory houses were made by the Detrick & Harvey Machine Co., of Baltimore.

brief interval. The motion due to yawing and bad steering cannot be compensated; the helmsman should be cautioned to keep the ship steady on her course and much of that motion will usually be avoided. Any navigator will have no difficulty on this account, since all such yawing will necessarily be so limited that the heavenly body will not be lost to view in the field of the telescope, and an observer can easily judge by the regularity of the oscillations of the heavenly body when it is in the axis of the telescope. Such judgment is equally necessary in observations with a sextant and much more difficult than with the solarometer, whose cross hairs enable the observer to judge this with facility and accuracy.

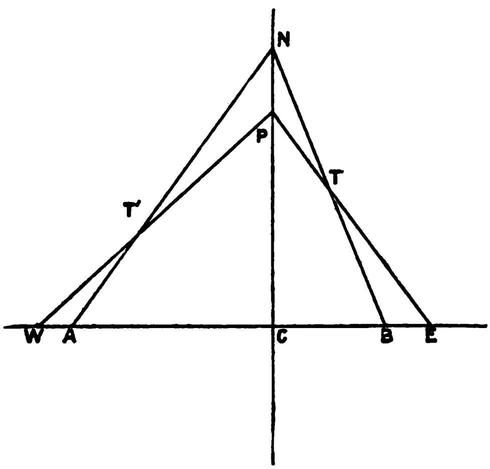
On board the U. S. Cruiser San Francisco the solarometer, after having been adjusted, was raised from its spindle and a fresh compass-rose placed on top of the float. It was subsequently found to be out of adjustment, and the results of a great many observations obtained by Lieutenant A. Ward and other officers, while agreeing uniformly within a few seconds, were about 2 minutes and 18 seconds in error in longitude, and with this difference that the longitude given by the forenoon observations was too far east by two minutes and 18 seconds, while the longitude by the afternoon observations was too far west by the same amount.

The error arose either because the instrument did not set vertically, or the arms of the latitude verniers were not horizontal. The striding level is furnished with each solarometer to determine if the instrument is properly carried on the float, but upon examination this spirit bulb had become useless on account of the evaporation of the alcohol from an almost invisible crack in the graduated glass tube.

As the San Francisco was about to sail for Europe and the striding level could not be replaced in Newport, the horizontal latitude verniers were adjusted by the amount of the error in the latitude ascertained by a meridian altitude of the sun.

The error in the latitude illustrates the well known effect of error in latitude on the longitude, and at the same time demonstrates the accuracy of the instrument and its thorough accordance with the mathematical principles.

In the sketch let the line *WA C B E* represent the equator, the line *NP C* the meridian, the lines *P T E* and *P T′ W* the plane of the declination circle with the pole at its proper elevation, and the lines *N T B* and *N T′ A* the plane of the declination circle of the solarometer out of adjustment, having the pole at *N* instead of being at *P*. The true hour angles were *C P E* and *C P W* for forenoon and afternoon observations. The solarometer out of adjustment gave those hour angles as *CNB* and *CNA*. *T* and *T′* indicate the altitudes of the sun at those observations.



The longitude at anchor at Newport being 4 h. 45 m. 19 s., and taking the observations, they had in the forenoon :

G. App't time,	2 h. 53 m. 09 s.	instead of	G. App't time,	2 h. 53 m. 09 s.
L. App't time,	10 h. 10 m. 08 s.		L. App't time,	10 h. 07 m. 50 s.
Long. by Sol.,	4 h. 43 m. 01 s.		True longitude,	4 h. 45 m. 19 s.

And in the afternoon :

G. App't time,	7 h. 50 m. 09 s.	instead of	G. App't time,	7 h. 50 m. 09 s.
L. App't time,	3 h. 02 m. 32 s.		L. App't time,	3 h. 04 m. 50 s.
Long. by Sol.,	4 h. 47 m. 37 s.		True longitude,	4 h. 45 m. 19 s.

The error in the elevation of the pole having caused this difference in the longitudes on different sides of the meridian. This effect is the same as that upon which Table XXXVIII of Bowditch is calculated; the effect of an error of one minute in the latitude upon the longitude.

In order to obtain accurate results, it is necessary to read the graduations and verniers accurately. If any of the circles are set

carelessly and erroneously, it is absurd to expect correct results with any instrument of precision.

The instrument is, when once mounted, kept on its base constantly available for observations. It is not carried about, and therefore the most frequent cause of damage to instruments is obviated. Intelligent handling of the instrument to take observations cannot injure it, and its durability under these conditions is assured much more than is that of instruments which are packed in boxes and carried about after having been used.

THE SOLAROMETER DECK OBSERVATORY.

In order to protect the instrument from the wind and weather, and enable observations to be taken under all conditions of rolling and pitching at sea, a peculiar observatory is provided as shown in the illustration. This observatory consists of a sheet-metal cylinder six feet in diameter and twelve inches high, which is screwed by wood screws to the deck. The upper part consists of two parts joined together. The lower part is a cylinder six feet in diameter, fitted with rollers and clips to revolve on top of the concentric cylinder secured to the deck. This is three feet high and six feet in diameter. Upon this cylinder the upper part is supported. The upper cylinder is cylindrical, five feet in diameter, three feet high, with a flat conical top. The upper part sets with one of its surfaces in the vertical plane of the lower cylinder, so that the center of the upper cylindrical part is six inches in rear of the center of the lower cylinders. A door is made to fit in the rear surface of the two upper parts. To get inside, it is necessary for the observer to step over the lower cylinder that is secured to the deck. The front hemispherical section of the upper part is fitted with two movable shutters, which can be closed entirely or opened to any extent up to 180 degrees. On the ledge in front of the opening there is an adjustable wind screen which is three feet wide and eighteen inches high, fitted with two curved bracket arms so that it may be adjusted to any position from the vertical to the horizontal. Within the observatory, under the ledge, beneath the wind screen, there is a box to contain books and implements. The electric storage battery to furnish the light for the telescope and to read the circles is stowed within the stand of the instrument. The arrangement of the observatory permits an observer to observe

a heavenly body that is abeam, with the ship rolling and the wind from abeam, so that the wind screen will protect the instrument from being heeled over out of the vertical plane, and the top of the observatory will not obscure the body being observed. Or in case the body to be observed is ahead, and the wind is ahead, while the ship is rolling deeply, the wind screen will protect the instrument from the wind, and the opening of the shutters will prevent the body from being obscured by the sides of the observatory. In this house, which can be revolved so that a body can be observed in any direction from the ship, the instrument is always available for observations.

In the U. S. S. San Francisco, the solarometer has a peculiar cover of the same dimensions as the top of the base. It is made to open at the top and drop down and rest on the rim of the base, and to turn on rollers around the top, using one of the hemispherical lids of the top for a wind screen.

This arrangement is much smaller than the regular deck observatory, but is inadequate when there is any wind. In the solarometer observatory, the observer may enter and close the door and when he opens the sliding wings of the slit there is no draught of wind blowing through, and no effect of the wind upon the instrument.

The primary object of the navy is to train officers and men to fight the ships in time of war, but while training, much useful hydrographic and meteorological work has been done by the navy, and such work will always be done in time of peace.

The solarometer will be found to be a most useful aid in such utilitarian work. For surveying coasts, investigations of ocean currents, running lines of sounding in surveys and for ocean cables, and every phase of scientific research so well done by the navy, it is evident that the solarometer meets a demand for accurately locating the ship's position and compass error astronomically at all hours of the day or night, independent of the visibility of the sea horizon.

PRECAUTIONS TO BE OBSERVED IN USING THE SOLAROMETER.

First.—The clamp screw on the shaft of the declination circle must not be used to set the declination circle at any hour angle

except in the plane of the meridian circle at twelve hours when examining the adjustment of the instrument. When observing, this clamp must invariably be kept loose.

Second.—To change the altitude of the telescope the movement of the circles in azimuth, altitude and hour angle simultaneously must be done by moving the clamp block of the azimuth vernier in azimuth, except when the declination vernier is set near the pole, as is the case in observations of Polaris. In this case turn the declination circle and see that the azimuth clamp is loose.

Third.—The azimuth clamp and hour angle clamp on the shafts of the declination circle should be kept loose when changing the latitude or the elevation of the pole of the solarometer.

Fourth.—When not observing, the instrument should always be kept covered by its chamois skin cover to prevent dust, etc., from getting in on the bearings.

Fifth.—The float must not be used under any circumstances as a receptacle for any implements, pencils, knives, screw-drivers or adjusting bars, shades, etc.

Sixth.—The instrument may be cleaned by using a soft camel's-hair brush and piece of chamois skin. The instrument must be kept carefully dry and clean, but no vigorous rubbing to remove rust or oxidization on the surfaces of the circles should be attempted.

Seventh.—In case it should be necessary to dismount the instrument from the float, the set screw at the bottom, by which it is screwed to the column on the float, must be carefully unscrewed, and the instrument raised by grasping it under the azimuth circle and carefully twisting it slightly while raising it vertically. Before dismounting, the latitude should be set at zero, the declination at zero, and the hour angle in the plane of the meridian circle. The upper circles will then all be vertical, and all the clamp screws should be set taut.

To put it in its transporting box, the instrument should be lifted by grasping with both hands under the two hemispherical arms A and B. It should be lowered in the box vertically, holding it with both hands and fitting it on to the spindle in the bottom of the box. After the box is packed with the wooden side blocks, the space around the instrument should be filled with wads or bunches of ordinary newspapers. Excelsior and similar material is not

suitable, as small particles are liable to get in the shaft bearings. Bunches of soft newspapers make the best packing in the box for transportation by rail.

The importance of a constant available means of determining the compass error on board the modern steel vessels cannot be too strongly emphasized. Experience shows that no compensation of the compasses for the magnetism of the ship, nor any determination of magnetic effect upon the compass, will hold good for any length of time, or for great changes of position. The most constant observations are necessary in order that any confidence can be reposed in the compass, and even then its indications must be regarded with suspicion.

The compass error is obtained at present by time azimuth of the sun, observed by the alidade on the standard compass. This compass is now (in most approved patterns) a liquid compass in a bowl on gimbals. The alidade is fitted with sight vanes and a prism in which the observer is with difficulty obliged to find the sun, and then note the instant with his watch or chronometer. The observation is made in connection with a sextant to find the local time, since to find the sun's true bearing it is necessary to know the local time or the sun's hour angle.

The same results are obtained by such observations of the moon or stars, but in order to ascertain the true bearing of the moon or star observed, it is necessary to know that body's hour angle. This hour angle can, however, only be ascertained by elaborate calculation from a sextant altitude of the heavenly body. Sextant altitudes at night are, as has been stated, impracticable, and consequently at present it is only during sunshining daylight that compass error can be ascertained.

The solarometer thus incidentally accomplishes what is sought to be done by both the sextant and alidade, with the advantage of being available at night or in foggy weather, and obviating the necessity of any elaborate calculation; and besides this has the great additional advantage that whatever may be the result indicated by the solarometer, the observer can always know positively if his observations and results are right or not.

The inventor takes this opportunity to express his grateful appreciation of the assistance of brother officers and others in developing and perfecting this instrument.

Mr. G. W. Gail, of Baltimore, Md., generously promoted the enterprise by financial aid. The U. S. Lighthouse Board gave opportunities to test the original design on the steamer Violet. Mr. Malster, the builder of the cruiser Montgomery, further tested it on her trial trips. The director of the North German Lloyd Steamship Company gave facilities for sea trials on two transatlantic voyages in the S. S. Weimar. The Maritime Association of New York allowed the free use of the Maritime Exchange for an exhibition and lectures on the solarometer to the maritime community of New York for a period of two weeks. The American Line of U. S. mail steamers gave free passage to guarantee officers to try the solarometer on two voyages. The Cunard Steamship Company and the French Compagnie Generale Transatlantique have ordered solarometers on trial. The United States Navy Department has encouraged its development throughout, and put one on board the cruiser San Francisco.

This gratifying experience demonstrates the interest and general desire for the success of an instrument which can do what is claimed for the solarometer.

A thorough discussion and critical examination of the details of the solarometer and its appurtenances is earnestly invited in order that any imperfections may be revealed, and a perfect modern navigating instrument be evolved.

DISCUSSION.

The CHAIRMAN :—I have listened with great interest and pleasure to the description of the solarometer by its inventor, Lieutenant Beehler. This beautiful instrument which he exhibits to us represents, as I know, his patient labor for many years, and I desire to extend to him my congratulations on his success. Any plan or device to aid the navigator touches us very nearly, and we must regard it as of the highest importance. Although the solarometer is still in an experimental stage, the favorable reports of its practical working give promise of its future usefulness. The point of superiority in the instrument which especially strikes me is that it enables the navigator to ascertain the ship's position by observations of a heavenly body when the horizon cannot be seen. This is done by measuring from the zenith which is determined by the instrument. This property of the solarometer gives it a wider field than the sextant, and makes it available in cases when the horizon is obscured and the sun is shining overhead. I

should think it would be especially valuable on many occasions when vessels are approaching our coast in foggy weather, for at such times the sun often shines out for a few minutes although the horizon does not clear. It also increases the accuracy and value of night observations, which are usually uncertain on account of the badly defined horizon.

I am doubtful about the extreme accuracy which is claimed in the results of the observations with the solarometer, but even if it only enables the navigator to determine his position by astronomical observation within a few miles, when otherwise his only guide would be the dead reckoning, it will afford him most material aid in these times when the magnificent ships already afloat frequently run more than five hundred miles a day.

The fact that with the solarometer on board the American Line S. S. New York when she was proceeding at high speed, the instrument was unreliable on account of the vibrations, does not seem to me to be a serious objection. If it is important to determine a ship's position accurately, she can always be slowed down or stopped long enough to take an observation, and the result will probably be a saving of coal and time as well as a greater degree of safety.

If the solarometer proves to be a navigating instrument of practical value, with which a ship's position can be determined by astronomical observations with reasonable accuracy, when without its aid this could not be done, the inventor can justly feel that he has added greatly to the security of life and property on the ocean, and he will deserve the thank of all seafarers. I believe that a careful trial of the instrument under the conditions of actual service will prove its worth.

Commander WM. BAINBRIDGE-HOFF, U. S. N.:—There are now several refinements in the arts, applicable to ships and navigation, which permit such an instrument as is the solarometer to become of great value. In fact Mr. Beehler has gone a long way towards supplying a necessity which the increasing speed in ships demands.

The passing out of sails in vessels on the great trunk routes of the sea, the solving of the problem of steadiness of platform, and the ability to steer to within small angles by means of steam make the use of the solarometer possible. Now there are no sails or spars to interfere with an observer's vision. Great steadiness of platform is scientifically procured through our present knowledge of the value of the distribution of weights in ships, while mechanical helm appliances, together with the inertia of large ship-masses, make steering much more accurate than formerly.

In the last thirty years the speed at sea of steam vessels has been doubled. In the next thirty years, this speed may be doubled or trebled. If this proves so, the voyager of 1925 may see a speed of a mile a minute at sea. Again, we find the 2000-ton ship of 1855 has become has become the 15,000-ton ship of 1895; will it not become in the year we have indicated, a vessel of at least 75,000 tons, and cost perhaps in the unnum-

bered millions of dollars, and hold a countless number of souls? If a ship of this size and speed becomes the packet of the future, it becomes then necessary to know *hourly* where the ship is, and when you are without a horizon for more than a third of the time of her run of three days through fog, haze or mist, and for half the time certainly through the phenomena of night, it makes such an instrument as the solarometer of priceless value.

In these days there will be carried an *astronomer* who, like a pilot, will be ever on the watch, while a "ticker" on the bridge or in the captain's room will keep the commander at all times advised of the ship's position.

Commander F. A. Cook, U. S. N:—It would be presumptuous for me to attempt to criticise, after a merely cursory examination, an instrument which has been perfected after years of patient and intelligent study and labor. I do not intend to do so, nor can I see wherein it can be criticised from my present knowledge of it.

The solarometer is a success, and has been so proven from experiment and use at sea. It is built upon a simple and plain theory. It is an astronomical triangle mounted upon a pedestal whose base is in the plane of the horizon, and its practical use depends upon its ability to maintain a constant level when mounted on the deck of a vessel at sea. It is in this ability that the ingenuity and patience of the designer is shown.

In clear weather the work of the navigator is truly "plain sailing." It is when the horizon is obscured that his anxiety begins and constantly increases as he approaches the land. Who that has navigated, but has often experienced the provoking and perplexing condition of a clear sky overhead, but an obscure and unreliable horizon? Just such conditions more often confront one in the vicinity of land. The solarometer meets these conditions perfectly, gives the position and corrects the compass. It is of inestimable value, and ought to be found upon all ocean craft. Unfamiliarity with its use should be no argument against it. The designer frankly admits that in extreme cases of vibration in high powered steamers, and in heavy seas the solarometer cannot keep its level. Under these conditions, if it did, it is quite certain most observers would not. The correct thing to do under such circumstances would be to stop for the observation, —a small concession indeed to make for so important a result.

I sincerely trust the inventor may receive his just reward by finding his instrument universally adopted and in successful use.

Commander A. D. Brown, U. S. N.—The mechanical solution (*at sea*) of the astronomical triangle has long been greatly desired by the navigator. Numerous instruments for the purpose have been devised, but all have failed owing to the fact that the plane of the horizon could not be determined by them with a sufficient degree of accuracy. In the solarometer, as described by Lieutenant Beehler, this difficulty appears to have been entirely overcome. If the constant level of the base of this instrument can be preserved, as appears to be abundantly proven by the method of manu-

facture and the actual use of the machine, no further argument for its adoption would seem to be necessary. In these days of ships which are themselves huge floating magnets, the means of frequently and accurately determining the compass error has become an absolute necessity. This is unquestionably afforded by the solarometer, and its adaptation to stellar observations is a feature which should greatly commend it, as with its use it will be no longer necessary to go blindly along at high speed for ten or twelve hours every day without any means of ascertaining the true course and distance.

The navigators of the world are indebted to various officers of the U. S. Navy for many improvements in the exercise of their art, but it would appear to have been reserved for Lieutenant Beehler to devise an instrument which will render assurance doubly sure, will make the navigation of a ship a pleasure rather than a task, and will remove an immense weight from the commanding and navigating officers of all vessels that have what we may well call "the automatic position and compass error finder," as a portion of their equipment.

Lieut.-Commander J. G. EATON, U. S. N.:—Although I have studied the solarometer with a view to offering some technical criticisms, I shall confine the few remarks I offer more to the practical side of the question, and content myself with stating that I fully believe that the defects which now exist are entirely due to the difficulties of construction, and not to faults in the theory.

Every navigator, vexed and perplexed by dim horizons, must have prayed for some point *d'appui* more reliable than the shifting line where sky and waters meet. A visible zenith would prove a blessing to every sea observer who seeks to establish his position. Lieutenant Beehler has originated and developed in his solarometer an instrument which practically confers on the observer a horizon that neither land nor fog can obscure.

I have not seen the solarometer at work afloat, but I can speak of its accuracy on shore, and the results laid before you in this paper will show you that the instrument is reliable, and that by its use we may eliminate the unreliable true horizon, and gives in place thereof, an always determinable circle of reference.

The mechanical portions of the instrument are so well adjusted that even the preliminary trials have shown great accuracy. The results on the sea show that the results may be relied upon within the limits of the usual errors of observation. The correction of the errors due to refraction presents the greatest difficulty. The true path of a heavenly body, and this is the only path for which the co-ordinated circles can be used, must always differ from the apparent paths due to refraction. The empirical method of correction, that of using the squares of the reticule, appears crude and unsatisfactory for refined observations. No better method presents itself, but the use of the one advocated must detract from the value of the observation.

Unquestionably, as the solarometer becomes generally used, slight changes in sections, conducing to greater steadiness, with consequent facility of observation will suggest themselves. The instrument is still, though developed, in its experimental stage, and faults due to design and want of poise will be corrected as they are recognized.

As it stands to-day, the solarometer marks a wide departure from our present methods, and its results, creditable as they are, fail to show its great superiority over horizon sextant observations.

Lieutenant Beehler has invented, and I may add, well nigh perfected, an instrument which bids fair to revolutionize the accustomed methods of ascertaining a ship's position at sea. I do not regard it as essential, or indeed wholly practicable, to determine the latitude and longitude by single observations. But as to the essential points, the solarometer can do all that the sextant can, and besides, can be accurately used where the sextant, deprived of the horizon, is useless.

The great value of such an instrument to a man-of-war will be appreciated. The importance of correctly establishing the ship's position at any time, day or night, has greatly increased with the speeds now in use. Cases will readily occur to naval officers, where swift descents upon an enemy's coast or fleet must depend for their success, upon the correctness of the departure. Any instrument of navigation which eliminates the uncertainties of the day horizon, and gives us one at night which can be relied upon, will prove of inestimable value.

I fully believe that the solarometer does, or will do these very things.

Lieut-Commander RICHARD WAINWRIGHT, U. S. N.:—The advantages of the solarometer as may be gathered from Lieutenant Beehler's paper, are the constant level or base, which provides a means of taking observations independently of the visibility of the sea horizon, and the use of a mechanical means of solving the problems in place of solving them mathematically.

Many attempts have been made to solve the problem of ascertaining the latitude and longitude at sea when the horizon was obscured or invisible. Several attachments to the sextant have been patented, but none have proved very successful when brought into practice, although correct in theory. If Mr. Beehler has solved the problem and his instrument is capable of being handled practically, as well as being theoretically correct, his invention will be of great value to the mariner. The difficulty heretofore has been to handle a necessarily delicate instrument with sufficient skill to produce good results under the different conditions prevailing at sea. Some of us may remember that Professor Chauvenet held that there was no reason why as exact observations should not be taken with a sea horizon as with an artificial one. He stuck to his proposition until on a practice cruise, when he undertook to take sextant observations while the vessel in which he was cruising was under the influence of a

choppy sea. Then he expressed doubts as to the possibility of ever getting reliable observations at sea.

Mr. Beehler says: "The solarometer obviates elaborate logarithmic calculations and combines in itself a pelorus; so that it furnishes a complete solution of the entire problem to ascertain the ship's position and compass error in the space of time ordinarily required to observe the altitude by the sextant, and take its bearing with a pelorus." This sentence is misleading, as, in the first place, there are no elaborate calculations necessary in order to ascertain the ship's position from sextant observations; the calculations are simple and occupy but little time when the navigator is in practice. Again, the nature of the problem is such that the instrument cannot obtain, under ordinary circumstances, good longitude results and good latitude results from the same heavenly body at the same time. Either the body will be nearer the prime vertical and the hour angle will be good while the latitude will be bad, or it will be nearer the meridian, when the opposite will be the case. If we examine the method of taking observations it will be found that when the latitude is unknown it is necessary to take four observations before the correct hour angle is ascertained, and then, in spite of the inventor's claim, the latitude must be in doubt. To take the observations and compute the results, it is necessary to take out the same quantities from the nautical almanac and from Bowditch as when the sextant is used, except the dip, semidiameter and four logs. In addition, it is necessary to make a small calculation from the readings of the compass rose to obtain the true course. When four observations are required, I believe it would be as well, if not better, to work a Sumner with the instrument.

The necessity of allowing for refraction is another difficulty with this instrument. It is evident that it would require a very highly skilled observer to allow for the effect of refraction by the position of the heavenly body in the telescope. Except when the body is both high in altitude and near the prime vertical, when the effect of refraction can be ignored; tables must be consulted, and the hour angle and azimuth corrected. Unless high in altitude and near the prime vertical, only stars that have a declination within the limits of the sun can be used, or very large tables must be computed. This refraction is a very bothering quantity for the inventor, for it varies with different states of the atmosphere and during low-lying fogs the quantity given in the table may be far from correct at a time when the solarometer should be most needed.

The inventor further says: "And besides, this has the great additional advantage that, whatever may be the result indicated by the solarometer, the observer can always know positively if his observations and results are right or not." This is incorrect. By use of the azimuth tables taking the hour angle observed, and the latitude and declination used, if the azimuth found in the tables corresponds with the one observed, the instrument may be said to be in adjustment. Should the observation be taken

improperly or wrong quantities used, the error must be serious to be detected by the tables. The body might be observed slightly out of the center of the telescope, and if it were near the prime vertical, a latitude far from correct recorded without an apparent change in azimuth. The fact is with this instrument as with the sextant, the navigator may be sure that his results are in error. What he desires to know is within what limits he can rely upon his results. The main question to be determined for the solarometer is, Within what limits can it be relied upon, at night, or in the daytime, when the horizon is obscured and the sextant of no use? If the probable error is sufficiently small, the instrument is of great value.

I believe the claims made by the inventor are too large and that they are likely to retard the progress of the instrument in its way towards general adoption; for, when unexpected difficulties are encountered with a new instrument, it is liable to fall into disrepute. The value of the solarometer does not depend, fortunately, upon its doing away with elaborate calculations, producing absolutely accurate results or accomplishing impossible tasks. What must be known is, Can the instrument be used in ordinary practice, in spite of the vibrations, rolling, pitching and yawing of the ship? Will the many adjustments remain correct for a reasonable time within reasonable limits under ordinary conditions? These questions should be answered shortly with three instruments afloat, and, if answered favorably, the solarometer must be adopted by all vessels of sufficient size to afford a proper location. If the instrument prove reliable, it must serve to save enough coal to more than compensate for its cost in a few trips; and its value to commerce is beyond estimation when the additional security to life and property is brought in consideration.

Mr. John Martin:—Having made six transatlantic voyages in charge of a solarometer on board of the U. S. M. S. New York, my experience has demonstrated the practical success of this instrument, under all conditions, except when excessive vibrations of the ship disturbed the float to such an extent, that it was almost impossible to judge when the body observed was in the axis of the telescope.

The solarometer was mounted in the New York on the hurricane deck directly over the thrust bearings of the engines, and in that place the vibrations of the engines were transmitted directly to the deck upon which the solorometer was secured.

On the first round trip voyage from New York to Southampton and return, December 12, to December 29, there was so little clear sky that there was no opportunity to test the instrument. I myself had had but a few hours experience in observing with the instrument before I went on this voyage, and was not sufficiently familiar with the manipulation of the instrument to get star sights.

On three days at sea I got snap shots of the sun, and my results agreed to within six miles of those observed by the sextant; while in port at South-

ampton, and subsequently at New York, on January 1, I obtained perfectly accurate results by observations with the solarometer.

On the second round trip voyage, from January 2 to the 19th, experienced some clear weather on the eastward voyage, and obtained some good results, but in the long following seas, the engines *raced* to such an extent, that the excessive vibration often made it impossible to determine positively when the sun was in the axis of the telescope; many of the observations were found to be erroneous, and were discarded, as they did not show agreement with determinations by the sextant. Such results as agreed with the sextant closely, also agreed in the comparison of the computed and instrumental values of hour angle, latitude, declination and azimuth.

The steamer New York went to Newport News, Va., to be docked on January 20, and on this trip the ball and socket joint of the float was removed, and thereby a great deal of the effect of excessive vibration was compensated. Under ordinary conditions, the removal of this bolt prevented much of the vibration of the ship from being communicated to the float, and I thought the only difficulty had been overcome.

I sailed again for Southampton on February 13, and obtained a series of observations, in which throughout the voyage I was enabled to ascertain the ship's position and compass error, except at times when the vibrations were such that the results were indeterminate.

Captain Jamison, commanding the New York, was much interested in the solarometer, but during these winter voyages the sun was so rarely visible, and so low in the bank of clouds and horizon, that he had not sufficient time or opportunity to become so familiar with the instrument, that he could rely on its indications: though by carefully comparing the readings of the solarometer with the computed value of azimuth in the book of tables, he has positive evidence of the correctness of results.

The method of allowing for refraction by observing the body in the telescope as much below its axis as refraction elevated the body above its true position, was practiced in the first two voyages, but on the last voyage, much better results were obtained by accurately allowing for the refraction and observing the body directly in the axis of the telescope.

Captain Jamison expects to use the solarometer through the spring and summer, when he will have more time to familiarize himself with its workings, and its value will become apparent in foggy weather during the coming spring and summer weather.

The position of the solarometer on board the New York, is unfavorable because that part of the ship is subjected to greater vibrations than any other. A much better position would be near the pilot house, but there, other reasons prevented its being mounted, and in order to get it on board at all, it was necessary to yield and place it where it was most convenient and least in the way.

Lieutenant G. L. DYER, U. S. N.:—Mr. Chairman, I would like to hear some account of the inventor's own experience with the solarometer at sea.

Lieutenant BEEHLER, U. S. N.:—I made two round trips, transatlantic voyages, in the North German Lloyd steamer Weimar, from Baltimore to Bremen, in March and August, last year.

On the voyages I had solarometers which were subsequently greatly improved, but though imperfect instruments, I was able at times to obtain good results which demonstrated the practicability of the instrument.

In these instruments, by setting the arcs in positions corresponding to the computed values of the four quantities of declination, latitude, hour angle and azimuth, and waiting for the sun or star to be visible in the axis of the telescope, I could get accurate and reliable results. The defects of the instrument were removed in the subsequent design, but the experience demonstrated that the rolling and pitching motion of the ship was fully compensated by the arrangement of the float in the bowls.

A Hicks clinometer was fixed near the instrument, and observations were taken, and accurate results obtained, when the ship was rolled 20 degrees each way. At one time I tried to get observations when the ship was rolling deeply, 40 degrees each way, but the heel was so great that it was impossible for me to reach up so as to have my eye at the eye piece of the telescope. It would have been necessary for me to have been about 7 feet tall to reach over, but for all that, I could see the shadow of the sun shining in the field of the telescope, even when rolling 40 degrees each way. At this time, the Weimar was flying light, with very little cargo, and in a heavy sea. The instrument was mounted on the hurricane deck, about 42 feet above the water-line, and the rolling and pitching motions were fully compensated.

In reply to the criticism of Lieutenant-Commander Wainwright, in regard to the refraction, I admit that there is, and has been, considerable trouble with refraction, but no more, nor in fact as much, as with a sextant.

In developing the instrument, the question of compensating or correcting for refraction has been a serious one. I find that it is best to correct the hour angle by a correction from tables corresponding to the hour angle, polar distance and latitude, or altitude; these tables are not as long as at first seems probable, and can be readily applied. The accuracy of the table of refraction has been questioned, but the error is small. I was under the impression that the amount of moisture in the atmosphere would have a serious effect on its refraction, but I have in a letter from Professor Harkness the statement that in the most refined observations of astronomers the moisture of the atmosphere is neglected, the temperature and pressure determining its density and refractive power.

The criticism of the proof claimed by the agreement between the computed and instrumental values of hour angle, declination, latitude and azimuth, seems to overlook the fact that as with all other instruments of

precision, accurate results can only be obtained by careful and precise work. If the body observed is seen exactly in the axis of the telescope, and if the graduated circles are accurately read, it follows as an axiom that if the computed and instrumental values agree, the result is correct, and the observer has proof of the accuracy of his observation. This feature has been used to obtain results with an imperfect instrument, and the practice has demonstrated the correctness of the claim.

In conclusion, unless there is any other point which I may explain, I desire to express my sincere thanks for the kind expressions of approval, and good wishes of those who have discussed the paper. In this connection, I feel deeply sensible of the favorable consideration I have met with on every hand. I have often heard it stated that the Hon. Navy Department does not encourage inventors. My experience has been quite the reverse, for I have had no reasonable request refused, and have been encouraged in every way. Your kind attention is another evidence of this feeling, and I thank you all sincerely for this most flattering reception.

The lecturer exhibited and explained the various forms of the instrument, beginning with the early imperfect ones and ending with that at present set up for trial and use in the Naval Academy grounds. After tendering a vote of thanks to the lecturer for a very entertaining and instructive lecture, the meeting adjourned.

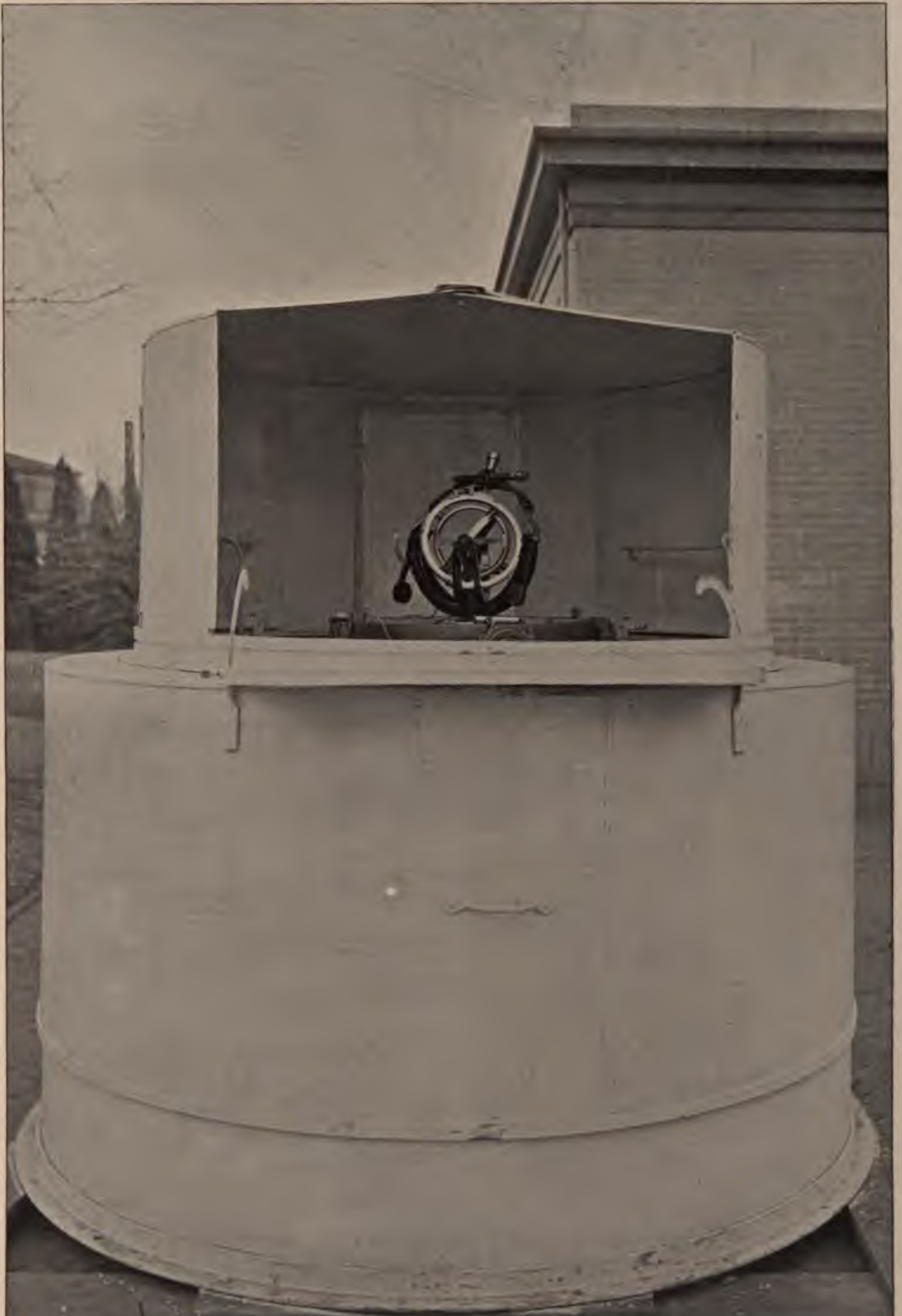


FIG. 6.—VIEW OF SOLAROMETER IN ITS OBSERVATORY AT U. S. NAVAL ACADEMY.

U. S. NAVAL INSTITUTE, ANNAPOLIS, MD.

ELASTIC STRENGTH OF GUNS.

By Lieutenant J. H. Glennon, U. S. Navy.

Much has been written on the subject of elastic strength of guns in the endeavor to make the subject perfectly clear, with the result that many books on the subject are filled with formulas. Lately the subject has been illustrated with geometrical diagrams quite as complicated as the formulas themselves, so that experts who examine them will probably find themselves wondering if, after all, they know anything about the question. It is thought that the subject may be presented in an elementary way without the use of many formulas, illustrating by numerical examples.

The basisof the modern theory is that within the elastic limit, that is, the limit at which if the load is removed a metal will assume its original dimensions, the strain (stretch or shortening per unit length) is proportional to the stress (or load per unit area). This is probably only approximately true for some metals. For example, some mild steel stretches less just within the elastic limit for a positive increment of stress than it does lower down. It seems to save up, so to speak, for a greatly disproportionate stretch just above the elastic limit; after this excessive stretch, the amount of strain for an increment of stress becomes nearly as small as below the elastic limit and then increases gradually till the ultimate load is obtained, the specimen breaking at a load somewhat lower than the highest point reached.

The highest stress obtained is the tensile strength and the stress that strains a metal to its elastic limit is the elastic strength of the metal (for extension or compression, as the case may be). A distinction should be carefully observed between the elastic strength of a metal and the elastic strength of a gun built of the

metal, the last being the pressure per square inch which, when applied to the gun internally, will permanently deform it by straining some portion of the metal beyond its elastic limit.

Following the ordinary custom, we will consider the strain within the elastic limit as proportional to the stress in the same direction, when this is the only stress applied. We will, moreover, only consider metals while acting inside their elastic limits, the various fundamental rules given applying only with this condition.

Within the elastic limit, then, if a thousand pound pull is given to a specimen of metal, and then a thousand more is added, the stretch for the second will be the same as for the first. This is equivalent to saying that the strain due to any stress is independent of prior stress. A second rule is that when a stress of tension (or compression) is exerted upon a metal, the strains in directions at right angles are $\frac{1}{3}$ of that in the line of the stress and are contractions (or extensions). The coefficient $\frac{1}{4}$ is sometimes used in place of $\frac{1}{3}$, but this latter is used almost exclusively by the Army and Navy ordnance bureau officers. If two or more stresses at right angles act upon a specimen, the total strains in each direction will be the algebraic sum of the strains in that direction, each component strain being independent of prior strain and each being readily calculated by the rule for the strains produced by a single stress.

The ratio of the stress to the strain caused by it in the same direction is called the modulus of elasticity of the metal and will be denoted by E.

It is necessary to use calculus only once in the subject of elastic strength of guns, namely, to get the fundamental formulas for tension and radial pressure.

The stresses acting upon a point in the thickness of a gun may be resolved in the three directions of the length, the thickness, and perpendicular to a radius of the gun and the length. Any point at rest is held by equal and opposite forces or otherwise it would move in the direction of the greater force. So that we may represent the radial pressure on any particle by two opposite and equal arrows pointed towards each other along a radius, and the circumferential tension at any point by two equal and opposite arrows pointed tangentially and away from each other. The longitudinal stress would likewise be represented by equal and opposite arrows in the direction of the length.

We will denote the radial stress by p, the circumferential or tangential stress by t and the longitudinal stress by q. Similarly, strains in the same directions will be denoted by $[p]$, $[t]$ and $[q.]$

If we denote the pressure inside of a closed cylinder by P_0, outside by P_1, the internal radius by R_0 and the outside by R_1, and suppose a plane surface passed through its axis, removing one half of the cylinder, it will be evident that the total tension of the cylinder at the points of junction with the plane must be $2(P_0R_0—P_1R_1)$ multiplied by the length of the cylinder, since this will be the total pressure on the flat surface tending to separate it from the half cylinder. But the presence of the flat surface will in nowise alter the forces causing stress in the cylindrical part, and this is evidently therefore the total tension throughout the two thicknesses of the original cylinder.

By dividing this quantity by the area of the section of the metal, we find the mean tension per unit area. A similar method of finding tension will apply to any cylindrical element, so that we readily find a differential expression and then, by integration, the law of radial pressures and tensions throughout the thickness. This is the occasion in the study of elastic strength of guns where we are compelled to use calculus. Such calculus as is necessary is however very simple, but we will not go into it here, and will consider the results only. They are for the varying radial pressure p at any radius r,

$$p=\frac{c_2}{r^2}-c_1, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and for the circumferential tension t at the same point,

$$t=\frac{c_2}{r^2}+c_1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The three conditions necessary to the deduction of these equations (which are absolutely independent otherwise of the metal) are uniform elasticity (or constant modulus), uniform longitudinal stress, and uniform longitudinal strain throughout the thickness. In them, c_2 and c_1 are constants. The longitudinal tension q is, following Clavarino, equal to c_1, and according to Birnie, zero. Birnie's assumption will give lower elastic strength generally and therefore being safer, is taken here. It seems moreover to agree more nearly with the facts.

Summing up the strains in the three directions as before indicated, that is, algebraically, we find for the strain $[p]$ in the direction of the radius (due to p and t),

$$[p]=\frac{1}{E}\left(-p-\frac{t}{3}\right)=\frac{2}{3E}\left(c_1-\frac{2c_2}{r^2}\right), \quad . \quad . \quad . \quad (3)$$

for the strain $[t]$ tangentially or circumferentially (due to p and t),

$$[t]=\frac{1}{E}\left(t+\frac{p}{3}\right)=\frac{2}{3E}\left(c_1+\frac{2c_2}{r^2}\right), \quad . \quad . \quad . \quad (4)$$

and for the longitudinal strain,

$$[q]=\frac{1}{3E}(p-t)=-\frac{2c_1}{3E}. \quad . \quad . \quad . \quad . \quad . \quad (5)$$

None of the resultant strains of the metal must ever exceed the elastic limit determined by dividing the elastic strength by the modulus of elasticity, or else the gun will be permanently deformed. These five equations are all that are necessary in the subject, if judiciously handled.

Example:—The internal and external radii of a tube are 3″ and 4″, the elastic strength of the metal for tension or compression (the two are usually taken equal for gun steel) is 60,000 lbs., and the modulus of elasticity (that for steel) 30,000,000. What is the elastic strength?

$$\text{The Elastic limit is } \frac{60,000}{30,000,000}=.002''.$$

The strain used will always be the greatest numerically since the elastic limits for extension and compression are assumed equal numerically.

Unless c_1 is different in sign from c_2, $[t]$ will always (see (3) and (4)), be numerically greater than $[p]$; $[t]$ or $[p]$, one of them, will be greater than $[q]$ numerically. The strain used will always be greatest numerically when r is smallest; that is, at the inner surface (see (3) and (4)).

We will first put the elastic limit equal to $[t]$, the strain circumferentially at the inner surface of the tube.

We have therefore, by (4),

$$.002=\frac{2}{90,000,000}\left(c_1+\frac{2c_2}{9}\right). \quad . \quad . \quad . \quad . \quad (6)$$

The external pressure is the atmospheric, which we will call o, and the greatest internal pressure that the tube can stand will be its elastic strength.

We have, remembering that the external pressure is o, $p=0$ when $r=4$. Hence, by (1),

$$0=\frac{c_2}{16}-c_1\,,\ \text{or } c_2=16c_1\,. \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

Substituting in (6) we find, $c_2=316,096$, and $c_1=19,756$; and finally, from (1), placing $r=3$ the internal radius, we have $p=15,366$ lbs., which is the elastic strength of the tube (as $[t]$ is the proper strain to use, being greater numerically than $[p]$ because c_1 and c_2 are positive).

To summarize the operation performed, we have assumed the internal strain and external pressure and found the corresponding internal radial stress or pressure.

Now suppose this tube is shrunk on another of radii 2″ and 3″ (about), the condition being that each tube shall stretch internally to its elastic limit when the maximum pressure acts. The internal pressure of the outside tube will be the external pressure of the inside tube.

Suppose the elastic strength of the metal for tension or compression of the inside tube to be 60,000. Then $\frac{60,000}{30,000,000}=.002$ is the limit of allowable strain. We place then, by (4),

$$.002=\frac{2}{90,000,000}\left(c_1+\frac{2c_2}{4}\right),$$

or,

$$180,000=2c_1+c_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

and, remembering that the pressure or $p=15,366$ lbs. when $r=3$, we have, by (1),

$$15,366=\frac{c_2}{9}-c_1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (9)$$

From these two equations we determine $c_2=172,417$ and $c_1=3791$ for the inside tube, and then the internal pressure or elastic strength by (1), whence $p=\frac{c_2}{4}-c_1=39,313$ lbs. In this tube c_2 and c_1 are both positive and the $[t]$ strain (as we find by trial, solving for c_2 and c_1) is the one to use. If the elastic strengths

for compression and extension are not the same numerically we may now try the values of c_2 and c_1 in (3), and see how $[p]$ compares numerically with $[t]$. If the ratio of $[p]$ to $[t]$ does not exceed the ratio of the elastic strength for compression to that for extension (and the order of work is based upon the fact that it generally does not), we have the correct elastic strength. Otherwise the elastic strength of the gun is limited by the compression of the inner points of the thickness in a radial direction, and we place $[p]$ equal to the elastic limit of compression (with its proper negative sign) and proceed as before.

If now there is a tube of 1″ inner radius inside, we take as its external pressure that last calculated and proceed as before. So that, given the dimensions of the various tubes of a built-up gun, we can readily calculate how much pressure the gun can stand. Taking the elastic strength of the metal as 60,000 lbs. for extension and compression as before, we have, by (4),

$$.002 = \frac{2}{90,000,000}\left(c_1 + 2c_2\right), \quad . \quad . \quad . \quad (10)$$

and by (1),

$$39,313 = \frac{c_2}{4} - c_1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

From these we find $c_2 = 57,472$ and $c_1 = -24,945$. Because of the difference in signs of c_1 and c_2, $[p]$ is greater than $[t]$, numerically, and these values are not the ones to use. We now place $[p] = -.002$ in (4), giving

$$-.002 = \frac{2}{90,000,000}(c_1 - 2c_2), \quad . \quad . \quad . \quad . \quad (12)$$

and from this and (11) we find $c_2 = 28,964$, and $c_1 = -32,072$ as the correct values of c_2 and c_1 for the inner tube. The elastic strength by (1) is $p = 28,964 + 32,072 = 61,036$ lbs.

SHRINKAGE.

The shrinkage is equal to the algebraic sum of the compression of the external diameter of the inner tube, and the extension of the inner diameter of the outer tube, the dimensions of only the two tubes in question at the time being considered. We consider the two tubes in question as they were before being put together,

and can then work to any condition in which they may be after being joined. Another way to state the same thing is that the shrinkage is equal to the algebraic difference of the extensions of these same diameters in working from the first to any final condition. How much is the inner tube of the above gun compressed externally by a pressure of 61,036 lbs. on the inside and 39,313 lbs. outside? The diameter would be compressed $\frac{1}{3.1416}$ times as much as the circumference, or by the product of the diameter by the strain $[t]$ per unit length of the circumference, taken with a minus sign (a positive compression is a negative strain).

The 4″ diameter of the inside tube will be compressed by (see (4))

$$-4\,[t] = -\frac{8}{90,000,000}\left(c_1 + \frac{2c_2}{4}\right) =$$

$$-\frac{8}{90,000,000}\left(-32,072 + \frac{28,964}{2}\right) = .00,156.$$

What is the extension of the second tube under the same circumstances, namely that caused by 39,313 lbs., acting inside at radius 2″ and 15,366 lbs. outside at 3″?

We substitute the value of c_1 and c_2 in (4), multiplying by the diameter and find the extension of the inside diameter to be (see (4)),

$$4\,[t] = \frac{8}{90,000,000}\left(3791 + \frac{172,417}{2}\right) = .008\,;$$

and the shrinkage is the first plus the second, or .00,956″. (The extension of the inner diameter of this tube need not be calculated in this way, since each unit of the inner circumference of the tube is strained to its elastic limit of extension).

In shrinking on the outside tube we shrink upon both the inner tubes. The shrinkage is the same as it would be on a simple tube of the same dimensions that could stand the same pressures inside and out. The question may be put: What would be the compression of the external diameter of a tube of 1″ inner radius, 3″ outer, due to a pressure inside of 61,036 lbs., and outside of 15,366 lbs.? What would be the extension of the inner diameter of the outside tube, 3″ inner and 4″ outer radius, due to an internal

pressure of 15,366 lbs., and an external pressure of 0 lbs.? Both of these would be found as before, it being noted that a new c_2 and c_1 would have to be calculated for the entire inner tube under the given conditions. The sum is the shrinkage.

The stretch depends on the dimensions and modulus of elasticity. Any tube will strain in exactly the same way as a simple tube of the same dimensions and modulus of elasticity. That is, we follow our original statement that strains due to any cause are independent of other strains already existing. In a simple tube we placed $[t]$ equal to the limit of strain to get our elastic strength. In no gun can we do more than place it equal to the numerical sum of the elastic limits for compression and extension. This represents the greatest scope through which a metal can work and more cannot be realized in any gun either through casting on the Rodman process, wire-winding or by other devices. The greatest strength that any gun can have is dependent on the amount of strain possible with the layer of metal next the bore. We work between elastic limits, and the best metal is reliable, homogeneous steel of the greatest difference between the two. Compressive strength is just as necessary as tensile strength. Difference between the two limits is what is required. In the Brown wire-wound gun, the inner layer has practically no elastic strength for tension. The excessive compressive strength of the staves, however, gives the gun a high strength, nearly as high in fact as that of another wire-wound gun with continuous metal next the bore, and having the same algebraic difference between the two elastic strengths.

The amount of elastic strain of which the metal next the bore is capable, is evidently $\frac{\theta + \rho}{E}$, where θ and ρ are the elastic strengths for extension and compression (numerically), and E the modulus of elasticity; and the greatest possible strength of a compound gun will be the internal pressure necessary to strain a simple tube of the same dimensions and modulus through this same amount. That is, when $[t] = \frac{\theta + \rho}{E} = \frac{2}{3E}\left(c_1 + \frac{2c_2}{R_0^2}\right)$ where R_0 is the inside radius, and $p = O = \frac{c_2}{R_1^2} - c_1$ where p and R_1 are the external

pressure and radius respectively, $p = \frac{c_2}{R_0} - c_1$ will give the greatest elastic strength possible with the gun of the given dimensions and modulus.

From these it will follow that a wire-wound gun will be weaker than another built-up gun of larger dimensions, but the same modulus, in which the same compression before firing of the same interior tube is accomplished. The greatest elastic strength possible with a gun of the same metal and same inside and outside dimensions as the one we have been using, calculated in this way, would be over 80,000 lbs.

Apropos of wire drawing it may be said that if a specimen of steel is placed in the testing machine and permanently strained by say 90,000 lbs. pull per square inch, and is then taken out of the machine and retested as a metal, it will now show over 90,000 lbs. elastic strength, and from its smaller original area in this last case, greater ultimate strength than before. Does this cold drawing increase its elastic strength for compression, or even keep it the same, and is the metal any better for gun purposes than it was before? If so, would it not be well to fire heavy proof charges, as in the old converted guns, and then finish bore and rifle the gun?

The effect of successive shrinkages is to continually compress the metal next the bore.

Now, in calculating the strength of the gun we found the pressures at contact surfaces when the maximum firing pressure (the elastic strength of the gun) acted on the inside, and o on the outside of the gun. If we take a simple tube of the same dimensions and modulus, and suppose the same firing pressure to act, the stresses and strains at the same radii will represent the changes in the stresses and strains of the compound tube, and by subtracting these from the final stresses and strains of the built-up gun, we obtain those in the gun when no pressure is acting. That is, in (1) we place p equal to the elastic strength of the gun, and r equal to the inner radius. Next we place $p = o$ and r equal to the outer radius; we thus have two equations and two unknown quantities, c_1 and c_2. Solve for these, and plot the curve shown by (1). The ordinates are the changes in radial pressure in the compound tube due to firing with a pressure equal to the elastic strength of the gun, and from these and the calculated pressures at the contact surfaces in the gun when in action, we find the pressures at rest by subtraction.

The pressure at rest on the outside of the inner tube is what causes the compression of the bore. In (1) we place p equal to this pressure at rest, and r equal to the outside radius of the inner tube. Next we place $p=0$ and r equal to the radius of the bore. From these two equations we find c_1 and c_2 as before. We substitute these in (4), making r equal to the radius of the bore, and the result is the strain (per unit) of the circumference, which is the same as the strain (per unit) of the radius, and by multiplying by the diameter (and taking the negative) we get its total shortening, or the total compression of the bore. The compression per unit should not exceed the elastic limit of compression. In the gun that we have arbitrarily assumed the increase in radial pressure at the contact surface of 2″ radius, caused by 61,036 lbs. inside and 0 pressure outside the gun, is 12,207 lbs. ($c_1 = 4069$ and $c_2 = 65,104$ for simple gun), and as the pressure during firing at this surface is 39,313 lbs., the pressure when the gun is at rest is $39,373 - 12,207 = 27,106$ lbs. Can the inside tube stand this pressure when the inside pressure is 0? We find under the given conditions that $c_2 = c_1$, that $27,106 = -\frac{3}{4}c_1$, and on the inside that $[t] = -.0024$, which is greater numerically than $-.002$, the elastic limit of compression. The tube would therefore be permanently deformed, and we cannot * build a gun of these dimensions and this metal so that in firing the interior of the second tube will be strained to its elastic limit. The shrinkage on the inner tube may be determined, however, to meet the condition that this is not deformed when the gun is at rest.

It should be noted that the pressure at rest outside the inner tube is due partly to the successive outside shrinkages. If, now, the compression per unit of the diameter of the bore is less than the elastic limit of compression, we may shrink on another hoop if desirable with such shrinkage as will bring the compression of the bore to this limit. Thus, in (4) we place $[t]$ equal to the strain (negative) required, and r equal to the inner radius. In (1) we place $p = 0$ and r equal to the inner radius of the gun. From these two equations we find c_1 and c_2, and substitute them in (1), making r the original outside radius of the gun (before putting on the hoop). The result is the pressure required between the original gun and the hoop.

* All strains being within elastic limits.

We have now the pressure at the surface of contact, and we require the shrinkage.

In (1), we substitute this pressure for p and the radius of contact for r. Next we place $p = 0$, and r equal to the radius of the bore. Solve for c_1 and c_2 (they have already been found, however,) and substitute in (4), making r the radius of contact. The result is the strain, and taken with a negative sign is the compression (per unit) of the outer diameter of the inside portion. In (1) we substitute the pressure at the surface of contact for p, and the radius of contact for r. Next 0 for p and the external radius for r. Solve for c_1 and c_2. Substitute in (4), taking r the radius of the surface of contact, and the result is the extension per unit of the inner diameter of the hoop. Add this extension to the preceding compression and multiply by the diameter, and the result is the required shrinkage. Various other problems might be solved in the same way but will not be gone into here. Our endeavor has been to avoid the usual nomenclature of books on the elastic strength of guns, which is something appalling, by the use of equations that will keep what we are doing clearly before us. Certain minor operations are duplicated in the description, which would not really be necessary with actual numerical cases, and it is thought that this adds to the clearness. It may be remarked that the pressures at the surfaces of contact of a built-up gun when the gun is at rest may be used to find the shrinkages, in exactly the same way as shown in this note using the maximum firing pressure. In fact, the corresponding pressures at these surfaces under any given conditions * may be used.

If two adjacent cylinders in a built-up gun have the same elastic limit, the most advantageous intermediate radius will be a mean proportional between the other two radii. The proof of this will not be given here as it would unnecessarily complicate what is intended only as a brief summary of the subject. Other considerations frequently interfere with this. For example, the jacket of a modern gun is made of sufficient thickness to withstand the longitudinal pull between trunnions and breech block. If P_0 and R_0 are the elastic strength of the gun and the radius of the exposed

* Attention is called to this by Captain J. P. Story, U. S. Artillery, in his Elastic Strength of Guns. It may be stated here that the notation used for strains is his also.

nose of the breech block respectively, θ the elastic strength of the metal and R_1 and R_2 the interior and exterior radii of the jacket, $\theta\pi(R_2^2 - R_1^2)$ should be equal to or greater than $P_0 \pi R_0^2$, so that no unit area may be exposed to a lengthwise pull greater than the elastic strength of the metal.*

* It may be necessary to consider the strains. Tangential stresses decrease and radial pressures increase the longitudinal strain, so that the longitudinal stress, as here used, should give fair results. If strains are considered, they should be determined originally on the condition that the longitudinal stress of the jacket is the one here used.

PROFESSIONAL NOTES.

LEAK ARRESTERS FOR SHIPS.

Experiments made by Mr. Colomès, a French inventor, with cellulose applied to holes in the hull, induced the French Government to adopt his device to be used on board its war vessels.

The apparatus for applying the cellulose to the hole is extremely simple. It is composed of a steel rod, threaded on a part of its length, at the end of which is pivoted an iron piece, which, when at right angles to the rod, has the appearance of a pickaxe, one of the arms of this cross piece being heavier than the other. This cross piece has fixed to it an oval piece of flat iron covered on both sides with thick felt. A small conical bag, filled with cellulose and having a hole through its center, can be slid on to the rod. Back of this bag is applied a large washer, which is held in place against the bag by a nut which is pushed down the rod to the threaded part, where it engages the screw. When a leak has been located any man can seize a leak stopper corresponding approximately in size to the width of the hole. Then holding it with the lighter end of the pick toward him, so that the pick and oval plate lie alongside the rod, he can introduce it into the hole. He can avoid the rush of the water by standing to one side. As soon as the pick has passed through the plating the heavier end descends and the pick places itself across the hole while the pressure of the outside water forces it against the side of the vessel and throws the pick arm across the opening, so, resting on the plating around the hole, it affords a point of support, while the felt covered plate reduces the leak very much and makes easier the next operation, which consists in slipping the bag of cellulose, washer and nut over the rod, screwing down the nut till the bag of cellulose is compressed against the hole. The cellulose bag fills up all parts of the hole, no matter how irregular, as the great value of the cellulose consists in its absorbing water and greatly increasing its volume. This elastic mass makes a tightly applied mat over the hole, which cannot be accidentally disturbed or displaced. Should the hole not be more than 10 inches wide and several feet long, a number of leak stoppers can be used side by side so as to gradually fill the hole.

Three sizes of arresters are used: No. 1 for holes from 1¼ to 3 inches, No. 2 for holes from 3 to 6 inches and No. 3 for holes from 6 to 10 inches.

In order to practically demonstrate the value of the leak arrester, the Franco-American Cellulose Company of 831 Arch street, Philadelphia, erected at their works a set of tanks pierced with holes of different sizes and shapes. The first experiment took place last year before a board appointed by the Navy Department and a number of naval officers and naval constructors, among whom were Lewis Nixon, chief constructor of the William Cramp & Sons Ship and Engine Building Company, and Captain Constance, naval *attaché* of the British Legation in Washington. The leak arresters were to be placed in three holes cut in the sides of an iron tank. The smallest hole was circular with burred edges and was 2½ inches in diameter; the next was hexagonal, about 10 inches wide, its area being about 72 square inches; the third was very irregular in shape and about 21 inches long, the average width being about 5 inches and the area 85 square inches. It being understood that the stoppers are intended to be used from the inside of the ship, the tanks were supposed to represent the sea and the holes or rents were located at a depth of 10 or 12 feet below the water line, with a corresponding water

pressure. The tanks were kept full by means of a pump so as to preserve the same head of water during all the tests.

The time employed to effectually close the holes under a head of water of 12 feet was as follows:

1. 2½-inch hole .... 30 seconds.
2. 10-inch hole .... 1 minute.
3. 21-inch hole .... 3 minutes.

Another test made immediately after the above, using a water pressure of 9 feet, gave the following results:

10-inch hole .... 37 seconds.
21-inch hole .... 1 minute, 40 seconds.

During the latest tests made three leak stoppers were placed side by side, instead of two, in order to show that any number of leak stoppers can be employed to gradually decrease the leakage until the hole is under control.

It is said that after the test Constructor Nixon expressed his opinion as follows:

"The experiment was a signal success, and the holes were stopped in remarkably short periods. By the use of the Colomès leak stoppers and cellulose any leak in any vessel can be stopped before an appreciable quantity of water can rush in."

For holes of much larger area Mr. Colomès proposes to use a cellulose mat to be applied from the outside of the vessel. This mat resembles an ordinary mattress, filled with obturating cellulose and is made in several sizes. The side of the mat away from the side next to the ship is covered with water proof cloth in order to prevent too much water from filtering through the cellulose. On the sides and at the corners rings are fixed intended to receive guiding ropes. Such ropes should always be kept in readiness on the upper deck, bent and with the slack so arranged that they will fall under the vessel so as to hang from gunwale to gunwale. These ropes are to receive the mats as soon as a leak is discovered and located. The soft pliant nature of the cellulose lining of the mat enables the pressure of the water to force it into all parts of the opening, so that every crack is filled and the inflow automatically stopped.

The Franco-American Cellulose Company is now experimenting with a view to finding a non-combustible substitute for the woodwork of the cruisers and battle-ships of the navy.

EXPERIMENTS ON WIND PRESSURE.

The subject of wind pressure is one on which our knowledge at the present day is not only limited, but exceedingly vague, and carefully-made experiments, if but to investigate a single feature of the problem, are, therefore, of the greatest interest, and can hardly fail to add something new to our information. Mr. J. Irminger, C. E., Member of the Danish Society of Engineers, has determined, what it is believed no one before him has attempted to do, the amount of suction produced by a current of air striking a plane surface, or the surfaces of various bodies; and the results of his experiments form the subject of a paper with the above title, read before that society in the early part of last summer. These results are remarkable in showing how very large a percentage of the total effect this suction is, not only through its action on the leeward side, but on the windward as well. In fact, when the angle at which the wind strikes a plane surface is small, nothing but suction is produced.

The practical importance of these experiments are evident; they throw con-

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 1.—COMPLETE SET OF LEAK ARRESTERS.

FIG. 2.—SHAPE OF 21-INCH HOLE.

FIG. 3.—HOLE STOPPED.

siderable light on the subject of flight, which at present is engaging so much attention ; and in structural designing they point out the way to more rational methods. We have hitherto considered the resultant of the pressure only, but if that of the suction is also taken into account, the final resultant is changed both in amount and direction. Thus in the case of a roof, given below, the resultant of suction and pressure will tend to lift, and not overturn it, which is in accordance with experience.

Experiments on wind pressure have usually been made by causing the body subject to the pressure to revolve in still air. The author's experiments were made with a fixed body exposed to a current of air. This current was obtained by making an opening into a large chimney 100 feet in height and fitting to this opening a rectangular, horizontal wooden tube, 9 inches by 4½ inches in section, internally polished. The experiments were directed to ascertain the distribution of pressure over the surfaces both of planes (*i. e.*, solids of small thickness) and of bodies of various forms. Taking first the case of planes, the plane was represented in the experiments by two pieces of sheet iron, 4½ inches by 1½ inch, placed $\frac{1}{10}$ inch apart, and connected together along their edges so as to form a shallow, closed box. To the interior of this box a pressure gauge was connected by means of a small pipe. A number of small holes were made in both faces of the box of which one at a time was opened. By this means, the pressure guage registered the pressure at any desired point in the windward or leeward side of the box. The pressure-pipe formed an axle on which the box could be turned to any desired angle with the wind. By means of a valve in the wooden tube the velocity could be varied. The velocities employed were from 25 feet to 50 feet per second. Besides the plane above described, which occupied the full width of the tube, (and may therefore be considered to represent in the open air a plane whose width is very great in proportion to its length measured in the direction of the wind), another plane was experimented with, measuring only 2½ inches by 1½ inch. It should be remarked that the velocity of the wind was obtained from the observed normal pressures by reference to the ordinary tables. In the following tables based on the experiments, it should be especially noted that at small angles of incidence the effect of rarefaction on the leeward side (showing itself as suction) causes practically all the pressure on the plane, and that at so small an angle as 5° this suction is over $\frac{1}{5}$ of the total pressure (that caused by the wind direct, plus that caused by suction) on the same plane placed normally.

PLANE 4½ INCHES BY 1½ INCH (FULL WIDTH OF TUBE).

Angle of inclination of plane to direction of wind.	Proportion per cent. of total pressure produced on leeward side of plane, velocities of wind in feet per second being				Proportion per cent. of tot'l wind pressure to pressure on same placed normally (average).
	49.5	48.5	34	31	
5°	100	100	100	100	23
10°	82	83	90	91	45
20°	76	81	89	86	48
40°	65	67	68	70	75
60°	60	63	65	63	90
90°	56	58	56	59	100

PLANE 2½ INCHES BY 1½ INCH.

5°	100	100	100	100	12
10°	100	100	100	100	26
20°	95	99	91	90	52
40°	78	76	70	74	74
60°	60	55	55	56	90
90°	48	43	44	46	100

The total pressures agree fairly well with those of Professor Langley given in the Proceedings of the Royal Society for 1889. The variations are readily accounted for by the change in form, which has considerable effect, even with plane surfaces.

Doubtless in connection with the observed results at small angles of incidence, many readers will call to mind cases where, with a light beam wind and yards nearly square, a vessel under sail alone has made some phenomenal speed, unaccounted for except on the supposition that the real direction of the wind was from a point abaft its apparent direction. This, however, is no explanation at all, as will be seen by a little consideration. What is meant by the real direction of the wind, is only relative; it is the direction with regard to a fixed point on the earth's surface. The apparent direction of the wind is a resultant of two motions, and is the true direction with regard to a moving object on the earth's surface, namely, the ship. There is no more reason to take into consideration the direction of the wind with regard to a fixed point on the earth's surface, than with regard to a fixed point in space, and this latter is manifestly absurd. But much of the result of trimming yards fine for winds abeam is readily accounted for by the suction.

Probably the high speed of the ice boat is largely due to the same thing. The same is true of wind-mills.

It is observed that the bird holds its wing at an angle of 6° with the horizon; at this inclination the effect of the wind upon the under side of the surface is zero, while the suction acting on the upper side is equivalent to an upward pressure which sustains the bird. Moreover, the friction of the medium through which the bird moves is hereby reduced, and a current is produced acting towards the wing, and inclined upward at a small angle.

The following table gives the results of experiments on long prisms, placed with their axes at right angles to the wind. p is the total pressure on a long plane of width s placed normally to the wind, and of the same length as the prism. It has been shown that about 57 per cent. of p is due to rarefaction, causing suction on the lee side :—

Cross Section of Prism.	Total resultant Pressure in Direction of Wind.	Percentage due to Rarefaction.
Square of side s (wind parallel to side.)......	0.95 p	43
" " " s (" " " diagonal) ..	0.79 p	76
Circle of diameter s........................	0.57 p	72
Rhombus, presenting an angle of 60° to the wind, length of side s.................	0.25 p	82
Equilateral triangle, side s (wind parallel to side)................................	0.59 p	42
Equilateral triangle, side s (presenting apex to wind)............................	0.42 p	86
Equilateral triangle, side s (presenting base to wind)...........................	0.71 p	87

The following table refers to other than prismatic forms :—

Body Under Experiment.	Total Resultant Pressure in Direction of Wind.	Percentage due to Rarefaction.
Sphere.........................	0.31 of total pressure on disk equal to great circle	77
Sphere distorted by elongation in the direction of the wind to double the diameter in length, ends pointed and symmetrical......	0.08 of total pressure on disk equal to cross section..................	93

Body Under Experiment.	Total Resultant Pressure under Direction of Wind.	Percentage due to Rarefaction.
Cube of side *s* (wind parallel to edge)........................	0.80 of total pressure on disk, equal to face......	22
Cube of side *s* (wind parallel to diagonal of face...............	0.66 of total pressure on disk, equal to face......	55
Cylinder of height equal to diameter (wind perpendicular to axis)...	0.47 of total pressure on square disk, equal to section through axis....	50
Pyramid, square base of side *h*, height *h* (wind parallel to side of base).....................	0.78 of total pressure on disk, equal to maximum section perpendicular to wind..................	37
Pyramid, square base of side *h*, height *h* (wind parallel to diagonal of base)..................	0.55 of total pressure on disk equal to maximum section perpendicular to wind..................	55
Cone, height = diameter of base = *h* (wind parallel to base).....	0.38 of total pressure on disk, equal to maximum section perpendicular to wind..................	50

The method used with these bodies is similar to that described for plane surfaces ; the different bodies are hollow and made of thin sheet iron ; they are about 4½ in. long, and provided with three holes in a row in the middle of one side. A hollow axis passes through the center, and communication is made with the pressure gauge in the same manner as before.

In the case of the cylinder, which was examined by boring a single hole in it and revolving it gradually through 360°, it was found that pressure existed only between 0° and 35°, when the effect became a suction. Similar results were found for the sphere.

Models were also experimented with representing buildings with roofs of various forms, and diagrams are given showing the distribution of pressure over leeward and windward sides. In all cases rarefaction on the side is quite as important a factor in the actual resultant force on the building as is the positive pressure on the windward side. The case of the pitched roof making angles of 45° with the horizontal on which a horizontal wind acts at right angles to the ridge is particularly worthy of note, and furnishes some food for thought. The normal pressure on the lee side due to suction is more than three times as great as that on the weather side. The resultant pressure on the two faces [neglecting the walls of the building] is inclined upwards and is about three and one half times as great as that on the weather side. On the weather side, the pressure is greatest near the lower edge, diminishes uniformly and becomes a suction near the ridge.

A REDUCIBLE LIFE-BUOY, AND THE GALIBERT RESPIRATORY APPARATUS.

[*Le Yacht.*]

Up to the present time solid bodies have commonly been used for rafts. Now the fact is, that the specific weight of the lightest of these rafts or floats is not much less than that of water, thus making it necessary to give them a great volume in order to obtain an indifferent floating capacity. M. Galibert has

put them aside in constructing his buoy, which he has made of a special fabric perfectly water-tight and impermeable to water for several consecutive days. This reducible life-buoy has, when folded, a very small volume and an insignificant weight. It is easily inflated, and an air cushion is obtained, to which sailors have given the characteristic name of "turtle," owing to its shape and dimensions. The so-called personal buoy is so light, and presents such a small volume, that it may be kept in a small valise when the air is let out. Large buoys which have one thousand pounds resistance to submersion are so arranged that they can be immediately turned into a large raft, and be very useful in case of sudden shipwreck, taking the place of boats, which are often smashed in the breakers on landing, or which cannot be lowered owing to the position of the ship.

Another contrivance very useful in the equipment of a vessel is the "respiratory apparatus," which consists essentially of an impermeable bag constructed on the principle of the reducible buoy, and which contains a sufficient supply of air to permit the saving of life in an asphyxiating locality. This pure air reservoir fixed upon the back so as to permit of free motion, and having a tube connecting with the mouth, with a nose compresser or pince-nez, allows a person to breathe normally without taking in any of the vitiated atmosphere by which he is momentarily surrounded. Suppose, for instance, a case of fire on board the ship; the smoke reveals the locality of the fire, but prevents getting at its origin, and putting it out in the beginning. Provided, however, with the above apparatus, any one among the crew can go down in the hold, and thus arrest the progress of the conflagration. The same would be true in case of foul gases developing in coal bunkers or any other part of the ship. Both apparatus have been successfully tested, and have received the official sanction of the (French) Government. J. L.

BOOK NOTICE.

DESCRIPTION ET USAGE D'UN APPAREIL ÉLÉMENTAIRE DE PHOTOGRAMMÉTRIE. Par Le Commandant V. Legros. Paris, 1895.

Photogrammetry is the science of making photographs in which the perspective is *true*, and in which, therefore, the dimensions of the objects photographed can be readily measured. Its most general application is to surveying.

There are several claimants for the honor of inventing this application of photography to geodesy and, although of recent date, the history of photogrammetry is clouded with discussion. Frenchmen claim the honor for Colonel Laussedat, Germans for Dr. Meydenbauer. In Italy, the engineer Pio-Pagiurni identified his name name with the subject in a practical way, by making an extensive photographic survey of the Alps. That was in 1875; ten years later, Deville, in the United States, completed a similar survey in the Rocky Mountains that had lasted five years, and covered 63 square miles of territory.

Commandant Legros does not concern himself in his attractive little book either with history or polemics, but proceeds at once to explain, very clearly and concisely, the apparatus he has designed for photographic measurements. He disclaims any intention of adding a new instrument to the list that he says is already legion. "The point is this," he remarks, "we have sought only to make use of certain elementary means in such a way that they may be applied to all of the instruments now on the market."

A photographic survey is based upon the fact that a photograph taken with a suitable lens is a true perspective in which the focal length is the distance line. By drawing in the horizontal line and the principal vertical line, all the measurement taken on the ground may be taken from the photograph. The distance of the point of sight from the picture is the essential element in all the constructions.

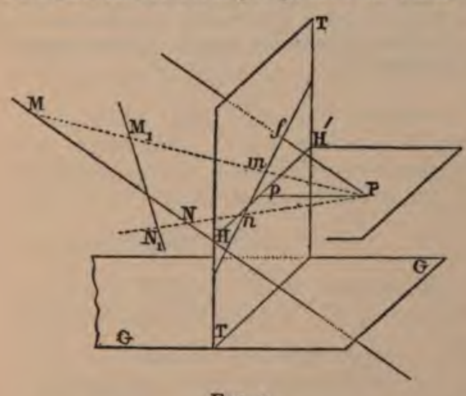


FIG. 1.

TT plane of picture.
P point of sight.
M a point in space.
m perspective of M.
If Pf is drawn parallel to MN, f is the vanishing point of the line.
PHH' plane of horizon.
p principal point.
HH' horizon line.
$Pp = d$ principal distance.

Every photogrammetric apparatus must be capable of tracing the horizon line, indicating the principal point and determining the exact focal length.

The construction of Commandant Legros' instrument will be understood from Fig. 2. The essential features of it are the graduated circle *K*, with its verniers and the ruled ground glass (*la glace quadrillée de précision*) in the swing-back *G*.

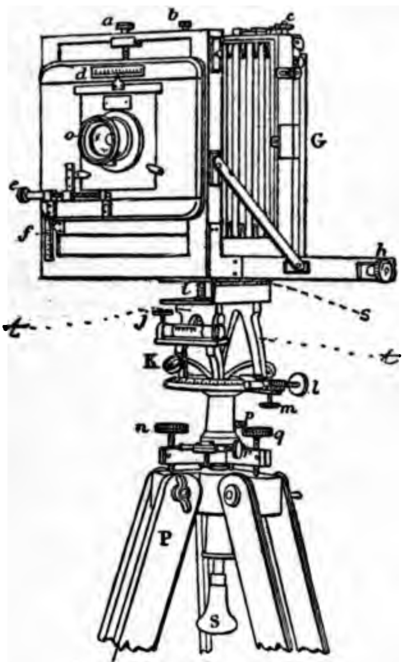


FIG. 2.

The camera is mounted on a double platform hinged at *s*, and supported by the uprights *t t*, fixed to the movable part of the circle. The axis of the swing-back is at right angles to that of the hinge, and the combination of the movements of the swing-back and hinge permit absolute vertical adjustment of the ground glass independently of the movement of the circle.

The ground glass is accurately divided into small squares by a double system of very fine parallel lines 1 cm. apart.

The lens has a vertical and horizontal movement by means of tangent screws *a*, *e*, the amount of which is measured in millimeters on the scales *d* and *f*. It is of the wide angle type and has a focal length of 5.51 in. to 5.707 in.; this corresponds to a plate 13 cm. by 18 cm. A lens of 20 cm. and an angle of 45° may be used with the same camera.

The instrument is easily adjusted, and as may be seen from the sketch, the attachments can be readily applied to any commercial outfit at slight expense. Among the other many advantages claimed for it by Commandant Legros, is the facility with which the horizon line and the principal vertical line are obtained, and the extremely simple method of determining the effective focal length. A. G.

BIBLIOGRAPHIC NOTES.

AMERICAN.

AMERICAN ENGINEER AND RAILROAD JOURNAL.

VOLUME LXIX., No. 1, JANUARY, 1895. Water-Tube Boilers and their Application to War Vessels. Aeronautics; Captive Lookout Balloon on Board the French Battleship Formidable (illustrated).

No. 2, FEBRUARY. Water-Tube Boilers, etc. (concluded). Aeronautics; United States War Balloons (illustrated).

It is said that Captain Glassford "hopes to be able to take up the flying machine at the point it has reached through the remarkable experiments of Hiram S. Maxim, and build a machine that will carry a navigator through the air and at the same time will be under full control."

BULLETIN OF THE AMERICAN GEOGRAPHICAL SOCIETY.

DECEMBER 31, 1894. The Cape York Iron Stone, by R. E. Peary, C. E., U. S. N.

CASSIER'S MAGAZINE.

DECEMBER, 1894. The New American Navy. Some Possibilities of the Storage Battery. Producer Gas for Steam Raising. How Iron is Made. Edison's Kineto-Phonograph. Manufacturing Machinery—or Building It. John Ericsson, the Engineer.

FEBRUARY, 1895. Recent American Direct Connected Engines and Dynamos. Preservation of Wood. Direct Electric Driven Machines. The Incandescent Lamp of To-day. Combined Efficiencies of Mechanical and Electrical Machines.

ENGINEERING NEWS.

VOLUME XXIII., No. 2, JANUARY 10, 1895. The Ritchie-Haskell Direction Current Meter. The Cost of Hydrographic Surveys.

No. 4, JANUARY 24. The Puget Sound Dry Dock, Port Orchard, Washington. The Seattle Lake Washington Ship Canal. Chemical Methods of Preventing and Extinguishing Fires.

No. 5, JANUARY 31. Rustless Coatings for Iron and Steel.

No. 6, FEBRUARY 7. Preservative Coatings for Iron Work. The Loss of the Elbe.

No. 7, FEBRUARY 14. Recent Experiments on Wind Pressure.

ENGINEERING-MECHANICS.

DECEMBER, JANUARY AND FEBRUARY, 1895. High Speed Steam Engines. Blowing Engines and Machinery. Calculation of a Compressed Air Transmission when the Subsidiary Losses of Energy are Taken into Account.

IRON AGE.

VOLUME LV., No. 1, JANUARY 3, 1895. The Colomès Leak Arrester for Ships. The Maxim Oil-Hardening Process. Decimal Sheet Metal Gauge.

To supplant the present confusing and annoying gauges for sheet metal.

FEBRUARY 7. The Best Metal for Field Magnet Frames.

JOURNAL OF THE UNITED STATES ARTILLERY.

VOLUME IV., No. 1, JANUARY, 1895, WHOLE No. 14. Geometrical Construction of Gun Strains, by Professor A. G. Greenhill.

There is no real difficulty in making any geometrical construction that may be desirable in connection with guns if the necessity for the construction is apparent. The figures here given are at least as intricate as the formulas used in present works, and it is not probable that they will supplant the latter to any extent. Every problem in gun construction can be solved by the judicious use of the original two-term radial pressure and circumferential tension equations; and simple geometrical constructions in connection with these to keep clear the various steps are very desirable. This, however, is quite different from a thumb-rule method of illustrating an equation, a method which has no more real connection with gun construction equations than with any other simple equations.

Development and Construction of Modern Gun Carriages for Heavy Artillery. The Buffington-Crozier Disappearing Carriage for 8-in. Breech-Loading Steel Rifle. Shall the United States have Light Artillery? Coast Artillery Fire Instruction, etc.

JOURNAL OF THE FRANKLIN INSTITUTE.

JANUARY, 1895. The Animal as a Prime Mover, by R. H. Thurston. The Resistance to Corrosion of Some Light Aluminum Alloys.

In strong salt solution, pure aluminum is best, but the German silver alloy stands highest among the alloys.

JOURNAL OF THE MILITARY SERVICE INSTITUTION.

No. 73, JANUARY, 1895. The Military Academy. Physical Training in British Army. Artillery Practice at Shoeburyness. Some Thoughts on Methods of Attack.

SCIENTIFIC AMERICAN.

DECEMBER 8, 1894. The Compass Field Glass.

DECEMBER 15. Traveling Military Turrets. The Warship Atlanta and her Magazine.

DECEMBER 22. Dry Dock at Port Orchard.

Will be the second largest dry dock in the world.

Trial of the Langley Aeoroplane.

It rose slowly in the face of the wind and sailed away for some distance.

DECEMBER 29. The Cramp Ship Yards (illustrated). Equatorial Stand for Small Telescopes.

JANUARY 5, 1895. Torpedo-Boats for the Cruiser Maine. United States Battleship Maine. American Armor Plates. Improved Gatling Gun. Preservation of Propeller Shafts.

JANUARY 12. The Battle of the Yalu River.

JANUARY 19. The New Warships Texas and Oregon.

JANUARY 26. The Electroplating of the Hulls of Iron Ships. Repairing Chinese War-Ships.

FEBRUARY 2. Cannon Magnets.

At a distance of 300 feet a compass needle was deflected 3° (the cannon and compass being in an east and west line).

STEVENS INDICATOR.

VOLUME XI., No. 4, OCTOBER, 1894. An Apparatus for Exploring Magnetic Fields as to Direction and Intensity, by Professor W. E. Geyer. The Determination of Carbon in Iron and Steel, by Professor T. B. Stillman. Experimental Determination of the Quickness of Action of a Shaft Governor, and Theoretical Consideration of the Influence of an Inertia Weight, by Professor D. S. Jacobus. The Manisman Process for Rolling Steel Tubes, by President Henry Morton.

THE UNITED SERVICE.

VOLUME XIII., No. 1, JANUARY, 1895. Recollections of Ericsson. The Organization and Administration of the Lines of Communication in War. Origin and Developments of Steam Navigation (continued). Notes on Photography, etc.

No. 2, FEBRUARY. China *versus* Japan. Organization of the Line of the Army. A Strange Wound. Origin, etc.

TRANSACTIONS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

VOLUME XV., 1894. Theory of Direct Acting Steam Pumps and Its Results. Use of the Indicator for Continuous Records in Dynamometric Testing. The Cumulative Errors of a Graduated Scale. Notes on Belting. Recent Progress in the Manufacture of Steel Castings. A Comparison of the Mean Effective Pressures of Simultaneous Cards Taken by Different Indicators. Crucible Furnace for Burning Petroleum. On the Maximum Contemporary Economy of the High-Pressure Multiple-Expansion Steam-Engine, by Robert H. Thurston. Experimental Determination of the Effect of Water in Steam on the Economy of the Steam Engine. Constants for Correcting Indicator Springs that have been Calibrated Cold. Some Experiments on the Effect of Water Hammer. Steam Piping and Efficiency of Steam Plants. Mechnical Education, by Eckley B. Coxe, President of the Society.

"If I wished to employ a young man in an engineering position, and had my choice between two equal in ability, age and health, of whom one thoroughly understood the fundamental principles of mathematics, mechanics, physics, chemistry and drawing, and the other was not so thoroughly trained in these, but had a college-shop experience and had gone through the regular courses upon the construction of locomotives, pumps, etc., and was able to discuss more or less intelligently all these different kinds of machinery, I should take the first. Although for the first year or so he might not understand as well as the other the details of the work he was engaged in, and might require more explanation and go slower, yet at the end of a couple of years, he would be far ahead."

A Note on Compressed Air. Power Losses in the Transmission Machinery of Central Stations. Cylinder Proportions for Compound Engines. The Theory of the Steam Jacket; Current Practice, by R. H. Thurston. Rustless Coatings for Iron and Steel. Corrosion of Steam Drums. Heat Units and Specifications for Pumping Engines. A New Recording Pressure Gauge for Extremely High Ranges of Pressures. Mechanical Draught.

FOREIGN.

ENGINEER.

VOLUME LXXVIII., No. 2031, NOVEMBER 30, 1894. English and French Quick-Fire Armaments. Wind Pressure. Peking (with map of city). Leading Articles: Flameless Explosives; Progress with Naval Contracts in Private Yards.

DECEMBER 7. The Siegfried, German Imperial Navy. Leading Articles: The Machinery of Warships; Instability of French Battleships; Foreign Ship Canals.

DECEMBER 14. The Chilian Cruiser Blanco Encalada (illustrated). Leading Articles: The Machinery of Warships; Face-Hardened Armor in the United States.

DECEMBER 21. Leading Article: High Pressure Compound Engines. Report of the Secretary of the U. S. Navy.

DECEMBER 28. The present Status of Face-Hardened Armor, by Captain W. T. Sampson, U. S. Navy (extract).

JANUARY 4, 1895. H. M. S. Magnificent and Majestic. U. S. Torpedo-Boats.

JANUARY 11. Shipbuilding in 1894. Third-Class Torpedo-Boats for the United States Navy.

JANUARY 18. Science in 1894. Midship Sections of H. M. S. Magnificent and Majestic, and the Influence of Bilge Keels.

JANUARY 25. The French Battleships Magenta and Hoche. Leading Articles: Modern Electricity; Recent Trials of French Cruisers.

FEBRUARY 1. Leading Article: The Machinery of Our Ships of War.

"It may be said that these were all small matters. They were nothing of the kind. Each was great enough in itself to lead to the capture of the vessel by an enemy's ship. In the history of the fleet of the mercantile marine, if we except the very earliest experimental days, we find nothing to parallel this. We do not for a moment pretend to say that ships do not break down; but we do say that the failures are few and far between, and that the Navy would do very well if the record was equally satisfactory."

Japanese Guns at Yalu.

FEBRUARY 8. Argon (the lately discovered constituent of the atmosphere).

Chemically this is the most inert substance known. It is possibly monoatomic, the ratio of its specific heat under constant pressure to that under constant volume being 1.63. Gaseous argon has a density of 19.90.

The Floating of H. M. S. Majestic. An improved Cartridge Closing machine. Leading Articles: The Baden Krupp Accident; Direct Action High Pressure Pumps.

ENGINEERING.

VOLUME LXVIII., No. 1509, NOVEMBER 30, 1894. Combined Dynamo and Turbine.

A combined dynamo and turbine has recently been built by Messrs. J. P. Hall & Co., of the Blackriding Iron Works, Werneth, Oldham. The dynamo and turbine are mounted on the same bedplate. The dynamo is designed to give an output of 50 ampères at 80 volts, when running at 730 revolutions per minute. It has an armature of the Gramme wire-wound

type, whilst the commutator segments are of hard drawn copper, insulated with mica. The brushes are of carbon, and the machine is so designed that the lead of the brushes may remain unchanged at all loads without sparking taking place. The field magnets are of wrought iron, and are shunt-wound. The electrical efficiency is about 86.33 per cent. The turbine is of the Girard type, and is intended to give 6 horse-power when supplied with 36 cubic feet of water per minute under a head of 120 feet. The guide ports are four in number, and can be closed successively by a revolving sluice, the spindle of which passes out through the turbine casing, and can be turned by an hydraulic cylinder, as well as by the handle.

Engineering in the United States Navy. The Bristol Recording Thermometer. Time Fuzes.

DECEMBER 7. The Machinery of Warships. Electricity on Shipboard.

DECEMBER 14. Canet Quick-Firing Artillery. The Strength of Short Boilers.

DECEMBER 21. The Guns for the New Spanish Cruisers. H. M. S. Magnificent. H. M. S. Ardent. Additions to the Navy.

DECEMBER 28. Torpedo Cruiser for U. S. Navy.

JANUARY 4 AND 11, 1895. The Application of Electricity to Working Ships' Turrets.

JANUARY 18. The Application, etc. (continued). Steam Life Boats. Flameless Explosives.

JANUARY 25. The Application, etc. (continued). The Engines of the Russian Ironclad Admiral Oushakoff. James Watt and Ocean Navigation.

FEBRUARY 1. The Application, etc. (concluded). The Coming Naval Estimates. The Cost of the French Navy.

JOURNAL OF THE ROYAL UNITED SERVICE INSTITUTION.

VOLUME XXXVIII., No. 201, NOVEMBER 15, 1894. Lessons from the Past for the Present. The Differentiation of a Naval Force: a Comparison. The Campaigns of Saxe.

DECEMBER 15. A New Method of Manœuvring "Controllable" Torpedoes or other Vessels when Absolutely Invisible to the Operator.

The position of the torpedo is plotted by a dead-reckoning method, the various courses being shown by an electrically controlled indicator. The question of irregularity of speed and current is not satisfactorily disposed of.

The Admiralty Flag. Naval Notes: Bow and Broadside Armament of Latest Types of French and English Battleships and Cruisers.

JANUARY, 1895. The Austro-Hungarian Manœuvres, 1894, Part I. The Vicissitudes of Regimental Colors, Part I. Notes on the Lee-Metford Rifle. Water-Tube Boilers. Naval and Military Notes.

The additional details of the Magnificent are interesting; also the new system of classification for the ships of the Italian fleet.

STEAMSHIP.

DECEMBER, 1894. Consideration on the Battleship in Action. Theory and Practice of Electrical Engineering. The Machinery of Warships.

FEBRUARY, 1895. The Design and Efficiency of Plant for the Transmission of Power by Electricity.

TRANSACTIONS OF THE NORTH OF ENGLAND INSTITUTE OF MECHANICAL AND MINING ENGINEERS.

Report of the Proceedings of the Flameless Explosive Committee. Part I.—Air and Combustible Gases.

UNITED SERVICE GAZETTE.

No. 3229, NOVEMBER 24, 1894. Places of Military Interest in the United States. The Machinery of Warships. Sea Power. The Magazine Rifle and its Tactical Use.

No. 3230, DECEMBER 1. The Training of the Navy. Capture of Port Arthur.

No. 3231, DECEMBER 8. The Engineer Staff in the Navy. Quick-Firing Guns and Projectiles.

No. 3232, DECEMBER 15. Coast Defence. Umpiring of Field Manœuvres. Effects of Modern Rifles. The Defensive Value of the Navy. Military Small-Arms of the World.

No. 3233, DECEMBER 22. Shipbuilding in the Royal Dockyards in 1894.

No. 3234, DECEMBER 29. The Surgical Significance of Modern Small-Calibre Rifles, I. The Fight Between the Yoshino and the Tsi-Yuen [on July 25]. The Effect of Modern Rifle Fire. Naval Rivalry. The Functions of the Army and Navy.

No. 3235, JANUARY 5, 1895. The Surgical, etc., II. A Naval Retrospect of the Past year.

The naval battle between the Japanese and the Chinese fleets off the Yalu, and subsequent events, conspicuously evidenced the advantage conferred by the possession of the command of the sea. Japan, once mistress of the sea, was able to land expeditionary forces practically at any portions of the enemy's coast line she desired, and the fall of Port Arthur was but a

natural result, with after consequences the magnitude of which we are not even yet in a position to judge. The importance was strongly emphasized of having a sufficiency of dockyards well supplied with all the requisite appliances for speedily restoring ships damaged in action to a condition enabling them to resume hostilities, as also was the very great desirability of there being on board of a warship a sufficiently strong and highly skilled body of engineer officers and mechanics capable of executing unassisted all but the most serious repairs, thus often avoiding the necessity of withdrawing a vessel from a station where her presence may be all essential, and at the same time lessening the pressure on the dockyards. Had the Chinese Navy been in a condition to resume hostilities at an early date, China might very well have been saved the bitter humiliation she now seems inevitably doomed to suffer.

No. 3236, JANUARY 12. The Surgical, etc., III. The Navy League.

No. 3237, JANUARY 19. The Military System of America. Woodwork in Warships. The Personnel of the Navy.

No. 3238, JANUARY 26. Lessons of the Franco-German War. The Health of the Navy, I.

No. 3239, The Health, etc., II. J. H. G.

LE MONITEUR DE LA FLOTTE.

No. 48, DECEMBER 1, 1894. The Inquiry Touching the Seagoing Torpedo-Boats. A New Petroleum Heating Method.

DECEMBER 8. Radius of Action of our Warships.

DECEMBER 15. Our Coast Defenses.

DECEMBER 22. The Inquiry Touching the Seagoing Torpedo-Boats (continued). The Navy in Parliament.

DECEMBER 29. The Inquiry Touching, etc. The French Navy in 1894.

JANUARY 1, 1895. The French Coaling Stations in View of the Madagascar Expedition.

JANUARY 12. Brueys and the Battle of the Nile. The Navy in Parliament.

JANUARY 19. The German Navy. The Extra-Parliamentary Board of Inquiry.

JANUARY 26. Our Colonies; Madagascar.

REVUE DU CERCLE MILITAIRE.

No. 47, NOVEMBER, 1894. Electric Searchlights and their Usefulness in Warfare (with sketch). Penetrating Power of the Modern Rifle. Infantry Practice (continued). Disciplinary Punishment in the Swiss Army.

NOS. 48, 49 AND 50, DECEMBER 2, 9 AND 16. Electric Searchlights and their Value for War Purposes (continued). Infantry Tactics (continued).

DECEMBER 23. Reorganization of the Italian Army. Electric Searchlights, etc. (ended).

DECEMBER 30. Lieut. Geraud's Field-Glass and Compass Combined. Infantry Tactics (ended).

JANUARY 5, 1895. The Regiments of the Cavalry Reserve and the Impressment Horses. The Loris Breast-Plate and the Dandeteau Rifle.

JANUARY 12. Platoon Instruction in the Artillery.

JANUARY 19. Long Distance Photography (sketches). Platoon Instruction in the Artillery.

JANUARY 26. Long Distance Photography (continued).

REVUE MARITIME ET COLONIALE.

DECEMBER, 1894. Our Commerce; our Countrymen in the Ports of the Atlantic, by Rear-Admiral de Librou. Influence of Sea Power on History, by Captain Mahan. Mission of the Upper Me-Kong; Report on the Trip of the Massie to Kemmarat, by Lieut. G. Simon. Description and Workings of the Hydraulic Apparatus of the 34-cm. Gun, Model 1887, in Closed Revolving Turrets, Mounted on Hydraulic Pivots, System Farcot.

"The late hydraulic apparatus furnished by M. Farcot, for vessels provided with closed turrets revolving on hydraulic pivots, differ to a great extent from those constructed up to the present. The installations described in this full and very interesting article refer specially to the cruisers Jemmapes and Valmy."

Vocabulary of Powders and Explosives (ended).

SOCIÉTÉ DES INGÉNIEURS CIVILS.

OCTOBER, 1894. Computation of Light Elastic Plates, and Action of Strings in Braced Ciment Beams.

NOVEMBER. Note on the Application of Aluminum to Naval Constructions. Seisms and Volcanoes. The Narrow-Gauge Roads in the Canton of Geneva.

DECEMBER. A Study of the Conveyance of Long Distance Energy through Electricity, and Electric Transmission by Continuous Currents. On the Experimental Determination of the Tension of Tie-beams in Arches.

LE YACHT.

No. 872, November 24, 1894 Effects of Artillery at the Battle of Yalu. A Reducible Life Buoy and the Galibert Respiratory Apparatus.

December 1. The China-Japanese War; the Battle of Yalu. The Taking of Port Arthur. The River Flotilla for the Madagacar Expedition.

December 15. The Navy in the Chamber of Deputies. The Positions of Belligerents at the Battle of Yalu.

December 22. New Maritime Incidents. The First-Class Cruiser Tourville.

December 29. The Battleship Magnificent. The Third-Class Cruiser Coëtlogon. The New Marine Boiler with Boiler-Tubes. A Table of the Ships in Commission on the 25th of December, 1894.

January 5, 1895. The War Navies in 1894. The Armored Coast Defense Vessel Jemmapes of 6600 Tons. The Stability of Route of Sailing Ships (A. Grenier). The Madagascar River Flotilla. English Constructions in 1894.

January 12. The War Navies in 1894 (E. Weyl). Stability of Route of Sailing Vessels. The Second-Class Cruiser Friant. Maritime Jurisprudence. Collision of Two Sailing Yachts.

January 19. Trials of War Ships (E. Weyl). Light Armor and its Substitutes. The Navy Yards and the New Constructions. The French Yachting of the Present Day. The U. S. Cruiser Minneapolis.

January 26. M. Felix Faure's Administration of the Navy Department. The French Yachting of the Present Day.

RIVISTA DI ARTIGLIERIA E GENIO.

Volume IV., November, 1894. Fortress Warfare (ended). On the Density of Air. Use of the Ordinary Tangent-Sight in Coast Firing. Study of a Quadrant with a Level of Precision. Artillery Action on the Battlefield in France, Germany, Austria and Russia.

December. On the Preservation of the Matériel in the Regiments of Field Artillery. Important Arguments Concerning Siege Ordnance The Use of Fortifications and Troops of the Engineer Corps on the Battlefield, and Lines of Investment. On the Approximative Research of the Center of Gravity of Ordnance, and the Projects in Course of Study (plates). Meteorology Applied to Military Art. Value of the Resistance of Air with High Initial Velocity.

RIVISTA MARITTIMA.

DECEMBER, 1894. A Few Considerations Touching the Loss of the Victoria. Electric Navigation (continued). Political Parties and Revolutions in Corea. The Naval Battle of Yalu. The Madagascar Question.

JANUARY, 1895. Situation of the Italian Merchant Marine. Pleasure Sailing in 1894. The Battle of Yalu Once More. The Madagascar Question.

REVISTA TECNOLÓGICO INDUSTRIAL.

DECEMBER, 1894. Explosions of Steam Generators. Tasks the Forensic Engineer Must Perform. Examination of the Plates (continued).

JANUARY, 1895. Explosion of Steam Generators, etc. Analysis of the Flour of Commerce.

BOLETIN DEL CENTRO NAVAL.

NOVEMBER, 1894. A Few Brief Historical Notes on Modern Naval Warfare. The Water-Tube Boiler. Vocabulary of Modern Powders and Explosives. Preliminary Notes for the Text of the Universal, and the Special Maritime Geography of the Argentine Republic (continued). J. L.

ANNALEN DER HYDROGRAPHIE UND MARITIMEN METEOROLOGIE

ANNUAL SERIES XXII., VOLUME XI. Tidal Phenomena in the Irish Channel. The Sailing Route from Sydney, Australia, to the Bismarck Archipelago, with a Description of the Coast of New Pomerania from Cape Gazette to Talili Bay, of the West and North Coasts of New Mecklenburg, and of New Lauenburg. Recent Observations with the Hydrometer. Justus Perthes' Sea Atlas. Minor Notices.

Meteorological Journals received during October at the German Observatory.

Weather Report of the German Coast for October.

SUPPLEMENT. The Coast of Tonquin. Information from the Latest Sailing Directions for Atshin. On the Methods of Finding the Altitude of a Star. Wilmington, North Carolinia. Voyage from Valparaiso to Honolulu via Callao. Voyage from Callao to Honolulu. Voyage from Swatow to Shanghai. The Approach to Taiwanfu, Formosa, and to Bullock Harbor, on the Chinese Coast. Minor Notices.

Meteorological Journals received during November at the German Observatory.

Weather Report of the German Coast for November.

DEUTSCHE HEERES ZEITUNG.

Nos 93 AND 94. New Regulations for Infantry in France. Modern Reserves (continued).

No. 95, NOVEMBER 28, 1894. The Battle of Yalu (a Review of Admiral Sir George Elliott's views on the Battle).

DEBEMBER 1. Modern Reserves (continued). Madagascar. Modern Reserves (continued).

DECEMBER 5. Foreign Squadrons at the Seat of War in China.

The strength of the different squadrons was, at the end of November, as follows: English, under the command of Vice-Admiral Fremantle, twenty-six vessels of all classes, of a total tonnage of 65,323. Russian, sixteen vessels, 46,791 tons displacement, carrying 106 heavy guns. French, eighteen vessels, including those at Saigon, 39,590 tons displacement, carrying 120 guns. Exclusive of the vessels at Saigon, France has only twelve vessels of 27,700 tons displacement, carrying 93 heavy guns. The United States has a squadron of eight vessels, all modern, except the obsolete Monocacy. These vessels displace 17,350 tons, and carry 64 heavy guns. The number of R. F. guns carried by the several squadrons will be of interest, in view of the important part that this type of guns played in the battle of Yalu. Of these guns, the English squadron carries 28, varying in caliber from 12 to 15-cm., and 113 from 4.7 to 6.5, or a total of 141 guns, exclusive of revolving cannon and machine guns. The Russian squadron carries 135 R. F. guns of moderate caliber, of which nearly one-half are 3.7-cm. guns.

The French squadron carries numerous revolving cannon and machine guns, but only sixteen heavy R. F. guns, of 10 to 16-cm. caliber, and fourteen of 4.7 to 6.5-cm. caliber. The vessels of the United States carry 41 R. F. guns, including those of 3.7-cm. caliber. Italy has sent a squadron of three ships of a displacement of 7096 tons, and carrying 50 guns, including 22 R. F. guns of moderate caliber. Finally, Germany had a squadron of five old vessels, which has since been augmented by two modern ships. The former displace 7824 tons and carry 36 heavy guns, and not a single R. F. gun, and only 12 revolving cannon. The addition of the latter increases the tonnage to 13,864, the number of heavy guns to 58, of which 8 are R. F. guns. Besides these guns, the increased squadron carries 8 R. F. guns and 24 revolving cannon.

With the vessels en route to the East Indies, the strength of the combined foreign fleet is 78 vessels, of a total displacement of 199,714 tons, carrying 561 heavy guns. The fleet carries 350 R. F. guns, of which 90 are of heavy caliber. Japan's Navy sinks into insignificance in comparison.

Modern Reserves (continued).

DECEMBER 8. The Capture of Port Arthur. Modern Reserves (continued).

DECEMBER 12. French Artillery Material. Modern Reserves (continued),

DECEMBER 15. The Proposed Increase of the German Navy for this Year. Modern Reserves (continued).

DECEMBER 19. A Critical Review of the Fleet Manœuvres of 1894. Modern Reserves (continued).

DECEMBER 22. A Reply to the Brochure "Unser Kadetten Korps." Modern Reserves (continued).

DECEMBER 26 AND 29. A Reply to the Brochure "Unser Kadetten Korps" (concluded). Modern Reserves (concluded).

JANUARY 2, 1895. Frederick the Great. Field Fortifications and Tactics.

JANUARY 5. Field Fortifications and Tactics (concluded).

JANUARY 12. A Russian Criticism of the Corps of German Officers.

JANUARY 16. German Water-Ways. A Strategical and Tactical Review of the Battle near Pressburg, 22d July, 1866.

JANUARY 19. The French Army. A Strategical and Tactical Review of the Battle near Pressburg, 22d July, 1866.

JANUARY 26. Military Attachés. A Strategical and Tactical Review of the Battle near Pressburg, 22d July, 1866.

MILITÄR WOCHENBLATT.

NO. 103, DECEMBER 8, 1894. Review of the Grand Manœuvres of 1894 in Germany (concluded). The Battle of Orleans (concluded). Mobilization of the Russian Army. The Strength of the French Army for 1895.

DECEMBER 12. The Battleship in the Battle off the Yalu River. The Mobilization of the Russian Army (concluded).

DECEMBER 22. A Brave Deed. The Effect of Field Artillery. The Riding School.

DECEMBER 29. The Effect of Field Artillery (concluded). The Riding School (concluded).

JANUARY 16, 1895. The Mobility of Artillery. Cereals for the Sustenance and Support of an Army. The Latest Changes in the Organization of the Italian Army.

JANUARY 19. The German Cavalry, 1870-71. The Mobility of Artillery (concluded). Shrapnel Fire of Field Artillery (a study). The Reverse Side of a Militia Army.

JANUARY 23. Concentration in Infantry Attack.

JANUARY 30. Changes in the Organization of the Army Corps of the Russian Army.

SUPPLEMENT TO MILITÄR-WOCHENBLATT.

VOLUME I., 1895. Von Moltke's Views on Flanking Manœuvres. The Disposition of Reserves in Battle.

MITTHEILUNGEN AUS DEM GEBIETE DES SEEWESENS.

VOLUME XXIII., No. 1. Speed and Turning Efficiency of Ships of War.

A discussion of the relative advantages of these qualities in actions between fleets and between single ships. The writer holds that the advantage will be with the ship or fleet that possesses the greatest turning power, and advocates in the construction of battleships increased steering power by the use of side rudders, to be operated either conjointly with or independently of the main rudder.

Naval Events in the War between China and Japan, including the Battle off the Yalu River.

A review of the events at sea, and a discussion of the battle off the mouth of the Yalu river.

The Pebal-Schaschl System of Electric Signal Telegraph for Ships. The Best Tactics to Develop the Fighting Power of the Gun, Ram and Torpedo in Actions between Ships, Groups and Fleets (translation). Gibraltar as a Base for the English Fleet. The German Naval Budget for 1895. The Dutch Naval Budget for 1895. The French Naval Budget for 1895. The French Battle-Ship Brennus. The Drezevecky Under-Water Launching Apparatus.

The trial of this apparatus on board the French cruiser Surcouf was successful.

Proposed Cruisers 3rd Class for the English Navy. Torpedo-Boat Destroyer Ardent. The English Cruisers Conquest and Carysfort. A New Torpedo Launching Apparatus Adopted in the English Navy. Launch of the Russian Armored Ships Poltava and Petropavlovsk. Petroleum as Fuel on Board Russian Warships.

The new armored cruisers Rostilav and Rossia will have their boilers fitted to burn petroleum ; and, if they prove successful, other ships will be similarly fitted.

The Trial of the Zalinski Pneumatic Gun in England. Death by Electricity.

No. 2. The Austrian Cruiser Empress and Queen Maria Theresa.

This protected cruiser has been recently completed and added to the Austrian Navy.

The English Naval Manœuvres of 1894. The French Naval Manœuvres of 1894. A Method to Determine the Position without the use of Logarithms. The Best Tactics to Develop the Fighting Power of the Gun, Ram and Torpedo. Defenses of Sarent. The Corinth Ship Canal. The Italian Battleship Re Umberto. The English Battleship Magnificent. The English Torpedo Boat Destroyers Ardent, Conflict and Dragon.

The first, on her official trial, developed a mean speed of 27.84 knots in six runs. The last two were launched at White and Laird's ship yard on December 15, 1894.

The French Submarine Boat Gustave Zédé. New French River Gunboats.

These boats have been designed and are building for use in the Expedition against Madagascar.

Proposed Increase of the Portuguese Navy. New Battleship for the Brazilian Navy. A New Man-of-War Harbor in France.

It is proposed to build a harbor at Port en Bessin.

A New Type of Whitehead Torpedo for the English Navy. A New Escapement for Watches. The Balloon at Sea. H. O.

REVIEWERS AND TRANSLATORS.

Lieutenant HUGO OSTERHAUS, U. S. N.
" ALBERT GLEAVES, "
Lieutenant J. H. GLENNON, U. S. N.
Professor JULES LEROUX.

THE CAPTURE OF WEI-HAI-WEI.

Reliable news in regard to the details of the capture of Wei-Hai-Wei is exceedingly scarce, and even the account of the sinking of Chinese vessels, previous to the surrender, is somewhat mixed.

The Japanese official account of the sinking, as we gather from a contemporary, runs thus:

"On the night of February 4, Monday, the first torpedo flotilla guarded the western entrance to Wei-Hai-Wei harbor, while the second and third flotillas, after the moon had set, made their way into the harbor through the eastern entrance. Having got inside the harbor, the boats torpedoed, and destroyed the large ironclad Ting-Yuen, whilst the bottom of the cruiser Ching Yuen is supposed to have been damaged. On the night of the 5th, the first torpedo flotilla renewed the attack, and torpedoed, and sank the cruiser Chih-Yuen," (this should probably be Ching-Yuen, as the Chih-Yuen was sunk in the battle of the Yalu) "and the large ironclad Chen Yuen" (this is an error, as the Chen Yuen was afterwards surrendered by Admiral Ting), "the Wai (Lai?) Yuen, and one of the gunboats."

The following, from the letter of a naval officer stationed on board a cruiser at Chefoo, will possibly indicate the answers to a few whys and wherefores unexplained as yet in the newspaper accounts with regard to the capture of Wei-Hai-Wei. The writer was not present on the ground, so of course writes only from hearsay evidence.

Wei-Hai-Wei fell on Monday, February 18; that is, on that day the final surrender took place. The day before, Admiral Ting, and the general in command of the forces, and a commodore whose names I forget, committed suicide. Admiral Ting took opium, the general swallowed gold (had to take opium afterwards to finish the task), and the commodore shot himself. This, that is, the shooting, is a very rare thing in China, as the Chinese like to leave their bodies intact.

Nothing was destroyed; the Japanese allowed the garrison to go, even furnishing a ship (one of the captured Chinese men-of-war) to convey the dead bodies of Admiral Ting, and the others, and the living frames of the various

European officers in the Chinese service to this port (Chefoo). The Japanese got the Chen-Yuen (7300 tons), two or three smaller men-of-war, six gunboats (Rendel system), and nine torpedo-boats (mostly Thornycroft), a machine-shop, the forts and their guns (a few were disabled by the Chinese), six bran new rifled breech-loading mortars for high angle fire (Krupp, 28 cm.) and a large amount of coal, food, clothing, rifles, ammunition, etc.

The defense of the place was almost farcical. We hear that the Japanese lost only a couple of hundred men on land and sea. They made no efforts to force the island forts, but turned their attention to frightening Chinese. In this, they were most successful; the sailors and soldiers (Chinese) absolutely refused to fight any longer.

Perhaps you will be amused at the account of the attack of February 7. This was given to me by an officer in the Chinese service. On the morning of this day, all the Japanese fleet placed themselves in front of the east entrance to Wei-Hai-Wei, and turning on their steam sirens and whistles, they fired all their guns (many of which were loaded with powder only) at the east entrance and the Chinese fleet. The forts on the mainland (also in possession of Japanese, having previously been captured by a Japanese army commanded by Field-Marshal Count Oyama) also opened fire, and the noise was terrific. The Chinese torpedo-boats turned and ran back through their own fleet and out through the other entrance and then dispersed, every man running for himself. The European officers, and the few men who remained in the island forts (the majority ran and hid) opened fire on their own torpedo-boats and sunk one of them. The others were all run ashore, the crews deserting, and running inland. The Chinese fleet started to follow, but did not go all the way out, and so were not lost. Not a shot from the Japanese during this "attack" struck any of the Chinese forts or ships. It was simply a scare, and a most successful one.

The famous torpedo-boat attack of the Japanese was directed by signals (lanterns, English Morse code) made by Chinese in the pay of the Japanese, who were serving in the Chinese forts.

The cowardice, ignorance and knavery of these Chinese "warriors" is almost beyond belief. They will run from a dozen men if they are only given the chance. The only obstacle the Japanese have is the weather. The winter is very severe; many days it is so rough that their ships have had to put out to sea, and their men have been unable to leave their quarters.

OFFICERS OF THE INSTITUTE,

1895.

Elected at the regular annual meeting, held at Annapolis, Md., October 12, 1894.

President.

REAR-ADMIRAL S. B. LUCE, U. S. N.

Vice-President.

COMMANDER A. S. SNOW,* U. S. N.

Secretary and Treasurer.

LIEUTENANT J. H. GLENNON, U. S. N.

Board of Control.

LIEUT.-COMMANDER B. F. TILLEY, U. S. N.
LIEUT.-COMMANDER U. SEBREE, U. S. N.
LIEUTENANT CHARLES E. COLAHAN, U. S. N.
LIEUTENANT G. L. DYER, U. S. N.
LIEUTENANT HUGO OSTERHAUS, U. S. N.
PROFESSOR N. M. TERRY, A. M., PH. D.
LIEUTENANT J. H. GLENNON, U. S. N. (*ex-officio*).

*Captain Philip H. Cooper, U. S. N., was elected Vice-President December 15, by the Board of Control, Commander Snow having resigned.

ANNUAL REPORT OF SECRETARY AND TREASURER OF THE U. S. NAVAL INSTITUTE.

To the Officers and Members of the Institute :

Gentlemen :—I have the honor to submit the following report for the year ending December 31, 1894.

Itemized Cash Statement.

Receipts During Year 1894.

Items.	First Quarter.	Second Quarter.	Third Quarter.	Fourth Quarter.	Totals.
Dues	$190 09	$1059 78	$327 00	$461 42	$2038 20
Subscriptions	43 05	198 70	371 75	47 60	661 15
Advertisements	123 75	206 25	70 00	148 14	548 10
Interest	117 50	9 00	45 50	120 09	292 09
Sales	119 05	143 75	40 70	76 25	379 70
Life membership fee	30 00	..	30 00	..	60 04
Binding	..	16 85	10 04	4 00	30 89
Protested check made good	..	..	..	6 00	6 09
Premium on foreign check	..	..	05	..	05
Half cost of Nos. des. by fire	..	..	..	57 94	57 94
Totals	$623 44	$1634 33	$895 04	$921 44	$4074 25

Expenditures During Year 1894.

Items.	First Quarter.	Second Quarter.	Third Quarter.	Fourth Quarter.	Totals.
Printing	$550 00	$1165 67	$880 48	$367 78	$2963 93
Salaries	270 00	230 00	310 00	280 00	1090 00
Postage, registering, etc.	18 78	53 85	53 57	25 99	152 19
Expressage	2 60	4 55	1 95	5 00	14 10
Freight and hauling	3 69	4 19	3 42	2 96	14 26
Expense, business trips	2 75	5 15	..	5 40	13 30
Expense on articles	8 35	2 00	..	..	10 35
Office expenses	1 05	5 94	.	..	6 99
Stationery	10	..	94	1 00	2 04
Binding	16 45	..	..	22 50	38 95
Prize (annual)	100 00	..	..	..	100 02
Gold medal	13 50	..	..	..	13 50
Purchase of back numbers	4 40	..	..	..	4 40
Telegraph, telephone, etc	..	58	29	15	1 02

EXPENDITURES—*Continued.*

Items.	First Quarter.	Second Quarter.	Third Quarter.	Fourth Quarter.	Totals.
Engraving medal and for case..	..	$4 00	..	..	$4 00
Purchase of Magazine for copy.	..	50	..	..	50
Advertising..................	..	..	$32 80	..	32 80
Protested check..............	..	..	6 00	..	6 00
Purchase of back numbers......	..	..	..	$6 50	6 50
Disct. on foreign money order..	..	03	..	..	03
Totals....................	$991 67	$1476 46	$1289 45	$717 28	$4474 86

SUMMARY.

Balance of cash unexpended for year 1893	$5216 39
Total receipts for 1894	4074 25
Total available cash, 1894	$9290 64
Total expenditure for 1894	4474 86
Cash unexpended January 1, 1895	$4815 78
Cash held to credit of reserve fund	132 89
True balance on hand January 1, 1895	$4682 89
Bills receivable for dues 1894	694 85
" " " back dues	795 00
" " " binding	26 40
" " " subscriptions	137 45
" " " sales	34 00
Value of back numbers (estimated)	2000 00
" " Institute property	100 00
Total assets	$8470 59

The liabilities of the Institute consisted on January 1st of the bill for printing No. 72, which had not been delivered on that date.

RESERVE FUND.

United States 4 per cent. Consols, registered	$ 900 00
District of Columbia 3.65 per cent. registered bonds	2000 00
Coupon bonds	450 00
	$3350 00
Cash in bank uninvested	132 89
Total Reserve Fund	$3482 89
Number of new life members	3

Membership.

The membership of the Institute to date, January 1, 1895, is as follows: Honorary members, 6; life members, 109; regular members, 576; associate members, 199; total number of members, 890.

During the year 1894 the Institute lost by death, resignations and dropped, 38 members. 63 new members' names were added to the rolls—50 regular, 13 associate; 2 regular, and 1 associate member became life members.

Members Deceased since January 1, 1894.

Life Members.

Brush, Geo. R., Medical Inspector, U. S. Navy, November 29, 1894.

Regular Members.

Nes, D. S., August 13, 1893.

Much, G. W., Naval Constructor, U. S. Navy, August 17, 1894.

Bridgman, W. R., Captain, U. S. Navy, September 14, 1894.

Merriman, E. C., Captain, U. S. Navy, December, 1894.

Garvin, John, Lieutenant, U. S. Navy, December, 24, 1894.

Street, G. W., Asst. Naval Constructor, U. S. Navy, January 11, 1895.

Associate Members.

Bole, J. K., January 8, 1894.

Balch, Geo. T., Colonel, April, 15, 1894.

Comly, Clifton, Major, Engineer Corps, U. S. Army, April 17, 1894.

Turtle, Thomas, Major, Engineer Corps, U. S. Army, September 18, 1894.

Copeland, C. W., February 5, 1895.

Publications on Hand.

The Institute had on hand at the end of the year the following copies of back numbers of its Proceedings:

	Plain.	Bound.		Plain.	Bound.
Whole No. 1	104	..	Whole No. 5	119	..
2	241	..	6	..	..
3	58	..	7	6	..
4	146	..	8	34	1

	Plain.	Bound.
Whole No. 9	38	1
10	4	..
11	215	1
12	52	1
13	2	..
14	4	..
15	..	..
16	224	1
17	1	..
18	105	1
19	108	1
20	126	1
21	223	1
22	268	1
23	178	1
24	183	1
25	1137	44
26	210	80
27	300	27
28	4	15
29	210	9
30	246	4
31	39	53
32	18	173
33	10	162
34	5	..
35	140	5
36	275	29
37	200	24
38	243	1
39	233	1
40	35	115

	Plain.	Bound.
Whole No. 41	260	19
42	108	19
43	159	3
44	57	10
45	42	19
46	50	19
47	31	19
48	54	18
49	19	17
50	62	17
51	38	18
52	58	16
53	152	34
54	4	4
55	58	17
56	544	55
57	22	20
58	6	7
59	17	10
60	..	1
61	194	18
62	143	16
63	233	44
64	40	19
65	127	18
66	6	16
67	11	15
68	200	9
69	227	16
70	228	18
71	276	16

1 Vol. X., Part 1, bound in half morocco.

Very Respectfully

J. H. Glennon, *Lieutenant, U. S. Navy,*

Secretary and Treasurer.

SPECIAL NOTICE.

NAVAL INSTITUTE PRIZE ESSAY, 1896.

A prize of one hundred dollars, with a gold medal, is offered by the Naval Institute for the best essay presented on any subject pertaining to the naval profession, subject to the following rules:

1. The award for the prize shall be made by the Board of Control, voting by ballot and without knowledge of the names of the competitors.

2. Each competitor to send his essay in a sealed envelope to the Secretary and Treasurer on or before January 1, 1896. The name of the writer shall not be given in this envelope, but instead thereof a motto. Accompanying the essay a separate sealed envelope will be sent to the Secretary and Treasurer, with the motto on the outside and writer's name and motto inside. This envelope is not to be opened until after the decision of the Board.

3. The successful essay to be published in the Proceedings of the Institute: and the essays of other competitors, receiving honorable mention, to be published also, at the discretion of the Board of Control; and no change shall be made in the text of any competitive essay, published in the Proceedings of the Institute, after it leaves the hands of the Board.

4. Any essay not having received honorable mention, may be published also, at the discretion of the Board of Control, but only with the consent of the author.

5. The essay is limited to fifty (50) printed pages of the Proceedings of the Institute.

6. All essays submitted must be either type-written or copied in a clear and legible hand.

7. The successful competitor will be made a Life Member of the Institute.

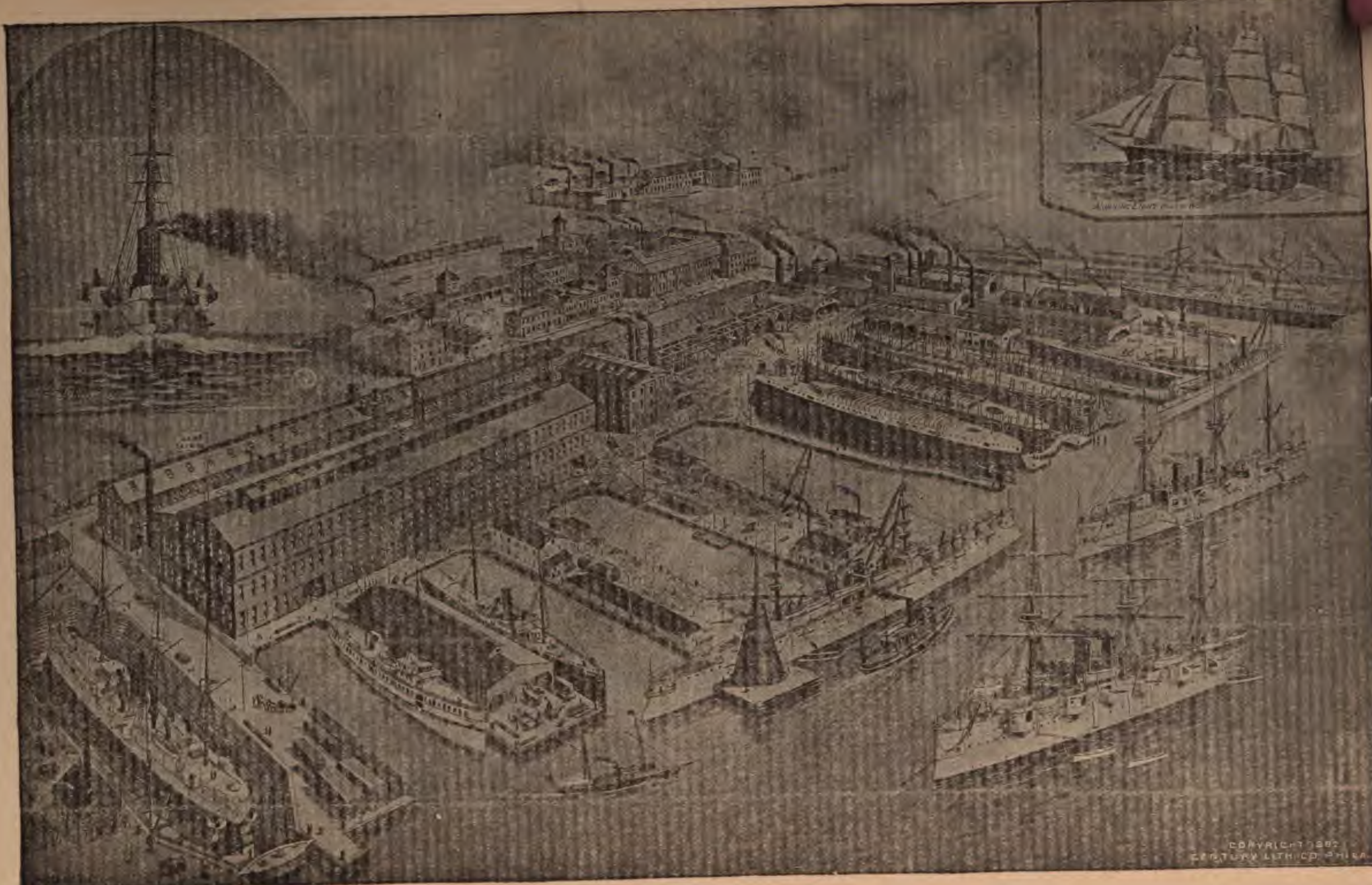
8. In the event of the Prize being awarded to the winner of a previous year, a gold clasp, suitably engraved, will be given in lieu of a gold medal.

By direction of Board of Control.

J. H. GLENNON,

Lieut., U. S. N., Secretary and Treasurer.

ANNAPOLIS, MD., *January* 1, 1895.


COPYRIGHT 1892
CENTURY LITH. CO. PHILA.

NOTICE.

The U. S. Naval Institute was established in 1873, having for its object the advancement of professional and scientific knowledge in the Navy. It now enters upon its tewnty-secondyear of existence, trusting as heretofore for its support to the officers and friends of the Navy. The members of the Board of Control cordially invite the co-operation and aid of their brother officers and others interested in the Navy, in furtherance of the aims of the Institute, by the contribution of papers and communications upon subjets of interest to the naval profession, as well as by personal support and influence.

On the subject of membership the Constitution reads as follows:

ARTICLE VII.

SEC. 1. The Institute shall consist of regular, life, honorary and associate members.

SEC. 2. Officers of the Navy, Marine Corps, and all civil officers attached to the Naval Service, shall be entitled to become regular or life members, without ballot, on payment of dues or fee to the Secretary and Treasurer, or to the Corresponding Secretary of a Branch. Members who resign from the Navy subsequent to joining the Institute will be regarded as belonging to the class described in this Section.

SEC 3. The Prize Essayist of each year shall be a life member without payment of fee.

SEC. 4. Honorary members shall be selected from distinguished Naval and Military Officers, and from eminent men of learning in civil life. The Secretary of the Navy shall be, *ex officio*, an honorary member. Their number shall not exceed thirty (30). Nominations for honorary members must be favorably reported by the Board of Control, and a vote equal to one-half the number of regular and life members, given by proxy or presence, shall be cast, a majority electing.

SEC. 5. Associate members shall be elected from officers of the Army. Revenue Marine, foreign officers of the Naval and Military professions, and from persons in civil life who may be interested in the purposes of the Institute.

SEC. 6. Those entitled to become associate members may be elected life members, provided that the number not officially connected with the Navy and Marine Corps shall not at any time exceed one hundred (100).

SEC. 7. Associate members and life members, other than those entitled to regular membership, shall be efected as follows: Nominations shall be made in writing to the Secretary and Treasurer, with the name of the member making them, and such nominations shall be submitted to the Board of Control, and, if their report be favorable, the Secretary and Treasurer shall make known the result at the next meeting of the Institute, and a vote shall then be taken, a majority of votes cast by members present electing.

The Proceedings are published quarterly, and may be obtained by non-members upon application to the Secretary and Treasurer at Annapolis, Md., Inventors of articles connected with the naval profession will be afforded an opportunity of exhibiting and explaning their inventions. A description of such inventions as may be deemed by the Board of Control, of use to the service, will be published in the Proceedings.

Single copies of the Proceedings, $1.00. Back numbers and complete sets can be obtained by applying to the Secretary and Treasurer, Annapolis, Md.

Annual subscriptions for non-members, $3.50. Annual dues for members and associate members, $3.00. Life membership fee, $30,00.

All letters should be addressed to Secretary and Treasurer, U. S. Naval Institute, Annapolis, Md., and all checks, drafts and money orders should be made payable to his order, without using the name of that officer.